THE USE OF URBAN CHARACTERISTICS IN ESTIMATING INTERNAL TRAVEL PATTERNS

FEBRUARY, 1956
No. 2

by

John W. Barr

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

THE USE OF URBAN CHARACTERISTICS

IN ESTIMATING INTERNAL TRAVEL PATTERNS

TO: K. B. Woods, Director
Joint Highway Research Project

February 1, 1956

File: 3-17
C-36-54V

FROM: Harold L. Michael, Assistant Director

Attached is a report entitled "The Use of Urban Characteristics in Estimating Internal Travel Patterns." This report has been prepared by Mr. John W. Barr, Graduate Assistant in the Project under the supervision of Professor Harold L. Michael. Mr. Barr also utilized this study as a portion of his work for the M.S.C.E. degree.

Mr. Barr shows in this analysis that there is a probability of developing desire-line travel data from characteristics of the city and its people. Several similar studies are also being conducted in other places in the United States. The Committee on Origin-Destination Surveys of the Highway Research Board is very interested in the results of this study. It is anticipated that a paper covering this project will be prepared by Mr. Barr for the 1957 annual meeting of the Highway Research Board.

The report is presented to the Board as information, and as consummation of a plan of study approved on July 13, 1955.

Respectfully submitted,

Harold L Michael

Harold L. Michael, Assistant Director
Joint Highway Research Project

HLM:cjg

Attachment

cc: J. R. Cooper
J. T. Hallett
F. F. Havey
G. A. Hawkins
G. A. Leonards
B. B. Lewis
R. E. Mills
B. H. Petty
Lloyd Poindexter
C. E. Vogelgesang
J. L. Waling

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

http://www.archive.org/details/useofurbancharac00barr

THE USE OF URBAN CHARACTERISTICS IN ESTIMATING INTERNAL TRAVEL PATTERNS

by

John Wallace Barr

Graduate Assistant

Joint Highway Research Project

File: 3-17

C-36-54V

Purdue University
Lafayette, Indiana

February 1, 1956

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the many persons who have contributed to this study. Particular thanks are due Professors H. L. Michael and P. E. Irick and other members of the faculty of Purdue University for their helpful suggestions and review of the manuscript, and Professor K. B. Woods and the Joint Highway Research Project for providing the opportunity to perform the study.

Appreciation must also be expressed for the cooperation of the Indiana State Highway Department, the Indiana Employment Security Division, the Logansport Chamber of Commerce, and other agencies assisting in the collection of data. The interest expressed and references supplied by Messrs. A. M. Voorhees, F. H. Wynn, and J. D. Carroll, Jr., are also greatly appreciated.

Gratitude is also expressed to Mr. R. J. Henning for his assistance particularly in the preparation of the illustrative material.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
ABSTRACT	viii
INTRODUCTION	1
PREVIOUS AND CURRENT INVESTIGATIONS	3
PROCEDURE	12
Traffic Survey Reports Used	12
Logansport, Indiana	12
Richmond, Indiana	15
Lafayette-West Lafayette, Indiana	18
Obtaining the Data	19
Investigations and Application	25
INVESTIGATION OF CORRELATIONS	27
Total Trips	27
Survey Area Population	28
Total Internal Trips	29
Total Work Trips	34

TABLE OF CONTENTS (continued)

Page

Tract Trips 35

Central Business District Trips 35

Residential Tract Trips 38

Trips Generated by All Tracts 56

Inter-Tract Trips 64

CBD-Tract Trips 65

Residential-Residential Trips 75

Residential-Industrial Trips 79

Trip Distribution 85

Trip Desire Satisfaction 86

Distribution Factors 87

Application 92

Total Estimates 93

Inter-Tract Estimates 94

CONCLUSIONS AND RECOMMENDATIONS 109

GLOSSARY OF TERMS 113

BIBLIOGRAPHY 117

LISTS OF TABLES AND FIGURES

List of Tables

Table		Page
1	Persons Per Passenger Car, Logansport Traffic Survey and Richmond Traffic Survey	32
2	Logansport and Richmond Population-Trip Data	42
3	Logansport Residential Tract Data	44
4	Richmond Residential Tract Data	45
5	Internal Passenger Car Trips Per Residential Acre	50
6	Logansport and Richmond Ownership-Trip Data	53
7	Tract Population - Trip Data.	58
8	Logansport CBD-Tract Trip Estimates	66
9	Richmond CBD-Tract Trip Estimates	67
10	Population by Half-Mile Rings	69
11	CBD-Tract Trip Lengths and Rates of Generation	73
12	Inter-Residential Trip Data	77
13	Logansport Residential-Industrial Trip Data	81
14	Richmond Residential-Industrial Trip Data	82
15	Trip Distribution by Land Use	88
16	Lafayette-West Lafayette CBD-Residential Trip Estimates. .	98
17	Inter-Residential Trip Estimates	101
18	Residential-Industrial Trip Estimates	104

List of Figures

Figure	Title	Page
1	Logansport, Indiana, Survey Area	14
2	Richmond, Indiana, Survey Area	17
3	Lafayette-West Lafayette Survey Area	20
4	Correlation of Trips and Area Populations	31
5	Correlation of CBD Trips and Area Populations	36
6	Correlation of Car Trips and Residential Tract Population	43
7	Correlation of Trips and Cars Per Dwelling	47
8	Correlation of Trips and Residential Density	48
9	Correlation of Trips Per Dwelling and Distance from CBD	49
10	Correlation of Trips Per Acre and Distance from CBD	51
11	Correlation of Trips Per Dwelling and Cars Per Capita	54
12	Correlation of Trips Per Capita and Cars Per Capita	55
13	Correlation of Internal Trips and Tract Populations	60
14	Logansport and Richmond Population Compactness	70
15	Correlation of CBD-Tract Trip Generation and Trip Length	75
16	Inter-Residential Tract Trips by City Ownership, and Trip Length	78
17	Residential-Industrial Tract Trips and Trip Length	83
18	Effect of Tract Size on Trip Distribution	90
19	Relation of Car Trips and Area Populations	95
20	Lafayette Population Compactness	96

List of Figures (continued)

Figure	Title	Page
21	Inter-Residential Trip Estimation Lines	100
22	Residential-Industrial Trip Estimation Line	102
23	Estimated and Actual CBD-Residential Desires	106
24	Estimated and Actual Inter-Residential Desires	107
25	Estimated and Actual Residential-Industrial Desires . .	108

ABSTRACT

The objective of this study was the reporting and discussing of certain investigations of relationships between urban characteristics and travel patterns. The primary sources of data were reports of recent traffic surveys of three Indiana communities having populations near or less than 50,000.

A thorough review of previous investigations and suggestions provided a guide for the procedure followed. A list of desired information was compiled, and the availability of population, employment, vehicle ownership, economic, and other data for the three studied cities is discussed. A number of values were found difficult, impractical, or impossible to obtain directly, and where these values were estimated, the estimation method is described and evaluated. Amounts of correlation existing between measuable characteristics and internal trips of the Logansport and Richmond, Indiana, area are discussed and shown graphically. The best or most basic relationships were used to obtain estimated trip patterns of the Lafayette-West Lafayette, Indiana area which are compared with values obtained by origin-destination survey.

Because of the number of estimated values involved and the fact only three cities were used, limitations are necessarily attached to the findings. In a sense, the limitations lend some significance to the results, in that better-defined data from a larger number of cities may be expected to result in more stable characteristic-trip relationships.

Several of the more important inferences are as follows:

1. Total internal trips and trips generated by the central business districts are related to city size but are affected by other factors.

2. Passenger car trips generated by residential tracts show a strong relationship with tract population. The rate at which trips are generated by these tracts appears to be affected more by vehicle ownership than by dwelling density or distance from the central business district.

3. Acreage of land use does not appear to be indicative of trip generation due to varying intensity of use.

4. Trips between the central business district and residential tracts, between pairs of residential tracts, and between residential and industrial tracts may be considered the basic trip movements of an area.

5. Trips between a central business district and residential tracts are largely accounted for by the combined effects of population compactness, vehicle ownership, and trip length.

6. Trips between residential tracts are affected by city size, ownership, and the populations of the two tracts.

7. Trips between industrial and residential tracts are related to the employment and population of the connected areas. Trip length has little effect on these trips.

8. Numerous additional factors can alter rates of trip generation within or between tracts and must be accounted for before trip patterns can be reliably estimated.

9. A great deal of research is required and warranted in order to arrive at a systematic procedure which may be used to reduce the task of analyzing internal traffic patterns.

10. The values which appear of greatest importance in trip estimation generally show trends which may permit predictions of their values at some future date.

INTRODUCTION

It has become evident to highway engineers and many other interested persons that traffic congestion problems are concentrated in and around urban areas. Unfortunately, it is also true that improvements of urban facilities are generally much more expensive and more complicated than rural improvements. Because of this, a sound foundation of factual data is a prerequisite for any modern highway improvement.

In planning a facility which is to satisfy at least the current needs of urban traffic, some idea is needed of the existing pattern of daily vehicular trips. Methods have been devised for gathering and analyzing information on the origins and destinations of trips within an area. Many techniques, however, are costly and time-consuming, even to the extent that the information may be outdated before it can be used. The recognized need for greater accuracy and efficiency in making origin and destination or O-D studies has led to research and resulting improvements.

At present, sample interview methods appear to be almost universally used for obtaining O-D information on trips which cross a cordon line enclosing a study area. There is less agreement as to the best technique for investigating internal trips, those which have both origin and destination within a study area. A sample, whether it be by roadside interviews, home interviews, or post cards,

is probably as accurate as and certainly more practical than an attempted census of such trips.

All trip sampling procedures presuppose that each trip sampled represents other trips which are similar to it, and therefore, that people under similar circumstances have similar travel habits or desires. Verification of this assumption has been the subject of much recent study and discussion, and there are increased indications that urban traffic volumes and patterns are related to urban size, spatial, economic, and land-use characteristics.

These relationships have been found to be useful in some cases in bringing outdated O-D information up to date and in predicting future trip patterns on the basis of the effect of trends on current travel patterns. However, there has been only a limited number of applications to cities with a population of 50,000 or less, and few, if any, attempts to use city characteristics alone to estimate trip volumes or patterns. Little is known, therefore, as to the usefulness of presently suggested measureable characteristics of a city in predicting or estimating the number and pattern of internal trips generated by each zone or tract. It is hoped that the results of the investigations herein reported will shed some light on this fascinating subject and will be of some benefit to those who may wish to utilize similar relationships to develop origin-destination patterns.

PREVIOUS AND CURRENT INVESTIGATIONS

Investigation of characteristics of urban travel has been the concern of most agencies which have conducted comprehensive traffic surveys of urban areas. However, this investigation usually has been carried out only to the extent that it results in a concept of the characteristics of travel in a particular city at a particular time. In general, there has been very little research conducted to attempt to answer the question: "Why was this trip made?" Recently studies have been made to determine what characteristics are common to all communities or to show that certain urban factors influence trip generation in certain cities. To date, not only is there no practical plan which can be followed to accurately estimate the volumes and pattern of trips generated by an area, but there has thus far been very little proof that travel habits are predictable under all conditions.

Since about 1949 the Yale Bureau of Highway Traffic has been conducting research concerned with investigating the nature of urban travel and measuring characteristics which appear to be related to trip movement (1)*. A large number of home interview O-D surveys, dating back as far as 1944, has been the source of data. In 1951 the late Theodore M. Matson, then director of the Bureau, showed the

---

*Numbers in parentheses refer to items in the Bibliography.

percentages of total vehicular travel attributed to various classes of inter-zone trips in 28 cities, and indicated how these percentages vary with urban area population (2). It is probable that the final results and conclusions of this research will contribute greatly to the general problem of urban travel analysis. Inasmuch as most of the cities studied are large, however, it is possible that the relationships may prove weak in application to cities under 50,000.

Mr. F. Houston Wynn, who directed the Yale researches, presented a paper at a Highway Research Board meeting in January, 1955, describing briefly some of the preliminary findings. A number of interesting inferences are discussed. It is shown that for the cities tested:

1. Total internal trips are correlated with urban area population.
2. Work trips are related to population but are also affected by vehicle ownership.
3. CBD* trips are related to urban population.
4. Trips attracted by the CBD decrease with distance, but the correlation is variable and depends on mode of travel, ownership at various distances, and the relation of the CBD to the population.
5. Trip generation is related to car ownership.
6. Trips generated by industrial tracts are partially explained by labor force, driving time, and population compactness.

---

*Hereafter, the central business district is referred to as the CBD.

7. Trips between residential tracts of mixed high and low ownership ratios are generated at a higher rate than those between tracts of high ownership or between tracts of low ownership. The latter are generated at the lowest rate.
8. Generated trips decrease as length of trip increases, following an apparent exponential decay pattern, with the rate of decrease least for CBD generated trips, greater for trips generated by industrial zones, and greatest for inter-residential trips.

A test of the net regression curves which were fit graphically to the data indicated that in three cities, ranging from 78,000 to 533,000 in population, the CBD car trip estimates were at least as good as the O-D survey data.

A slightly revised copy of this paper was presented by Mr. Wynn to the Institute of Transportation and Traffic Engineering at the University of California (3). Also included in this publication is the description of a general procedure which might be used in any city to develop desire line patterns without a detailed O-D survey.

In this latter article are included recommendations for preliminary steps which should be performed for an analysis of existing travel patterns, as well as suggestions for approaching the problem of estimating future patterns. Pedestrian, commercial, truck, and taxi trips, and trips within the CBD, and between the CBD and industrial tracts are discussed briefly and generally. "Person trips" (driver and passenger) by car and transit to and from the CBD, to and from industrial zones, and between residential zones are treated

more specifically. Reference is made to a system of successive approximations which may be used to distribute known or estimated zone-generated trip volumes to form an inter-zone pattern. Suggestions are made for procuring the data needed to apply correlations found in the Yale research, and for supplementing these data with special volume and parking lot counts, screenline and cordon counts and classification, cordon interviewing, and, when available, previous O-D data.

This approach has been used in the 1955 study of the Philadelphia metropolitan area by Mr. Wynn and Wilbur Smith and Associates. Improvements in the technique and a detailed description of methods are expected to result from this application. The relationships between work trips and car ownership and between ownership and family income have been indicated by this study as well as by studies of Washington, D.C., and ten Canadian cities, according to a paper presented by Wynn at a recent meeting of the American Society of Planning Officials in Montreal (4).

Similar relationships have been discovered during the traffic study of the Detroit metropolitan area. In a recent paper suggesting a series of steps which might be used in obtaining O-D data in a manner which would enable an analysis of traffic-land use relationships, Mr. Arthur T. Row has briefly described the approach used in the Detroit Study (5). By isolating pure land use units and computing trip volumes to these units it was possible to obtain values for trips per unit of employment, trips per net acre, trips per 1,000

square feet of industrial floor space, and other indices of generation. Trips per household, cars per dwelling, and trips per capita at various distances from the CBD were also computed. It is suggested that by projecting such measurements and land use characteristics, the traffic pattern at some future date might be predicted.

In a draft of part of the report on the Detroit Study (6) Mr. J. Douglas Carroll, the study director, suggests that a knowledge of land use will provide the linkage needed to translate the characteristics of trip generation into flow patterns. Based on very small areas of reasonably homogeneous land use, trips-per-acre data are shown by land use and by distance from the CBD. Further analysis indicates that the major land use of an area dictates the predominant purpose of trips to that area. Trips-per-dwelling in 254 zones were shown to be affected by cars-per-dwelling, distance from CBD, income, and dwelling density factors; inter-correlation of these factors was also found to exist. For the purpose of predicting interchange volumes, there is suggested a model equation based on the ratio of actual to potential trip interchange.

A description of this equation is made in an unpublished paper by Mr. Howard W. Bevis of the Detroit Study Staff (7). "Potential" or probability interchange is defined as that which could be expected to occur by chance if there were no factors to consider other than zone size. The ratio of actual to potential interchange is, then, a measure of "friction", which is dependent upon a number of socio-economic variables. A random sample of the internal trips

from the Detroit Study (only 7 per cent of the total trips were external) were used to relate the ratio to a number of these variables and thereby test the model. The sample consisted of 1,296 different pairs of zones. A high degree of correlation was found to exist between the friction index and over-the-road distance between zones, travel time, trip length between zones at various distances from the CBD, and trip length by mode of travel. Travel time was found to be highly intercorrelated with trip length. It is pointedly stated that additional research is needed to find more precisely the effects of changes in land use and spatial distribution, and to utilize the Detroit findings in studying any other urban area.

Since over-the-road trip length was found to be relevant in predicting trip volumes, another project during the Detroit Study was the investigation of the possibility of estimating inter-zone distances (8). It is suggested that the burdensome task of hand measurements between thousands of pairs of zones can be reduced. Possibly because of Detroit's street system, the airline distance was found to be better correlated with over-the-road distance than was right angle distance. Reasons are given for the probability that such estimates are no less accurate than hand measurements when there are many distances to be found.

Mr. Carroll, in another paper, discusses the definition of areas influenced by urban functions and the uniform effect of distance on trip volumes (9). Although examination of local conditions and natural barriers is recommended, urban influence is shown to be

generally inversely proportional to distance squared.

The general stability of O-D patterns during a change in volumes was indicated by a pair of surveys of the city of Miami (10). The two studies were made in different seasons between which there was a large tourist and transient traffic change. Messrs. M. A. Conner and S. H. Hiller, who directed the surveys, have suggested that the uniformity of volume change and general absence of pattern change indicated that O-D and parking information can be kept current and new data developed through knowledge of the effects which certain factors have upon trip generation or attraction. Among the factors mentioned were zone population, geographical location, economic level, land use, commercial floor space, and employment. It was observed that trip patterns may be affected by congestion, availability of parking space, the relationship of living, working, and shopping areas, and the travel time between zones.

Shopping habits and their influence on travel patterns have been the subjects of recent studies by the Automotive Safety Foundation and the Highway Research Board. At the 1955 meeting of the Board a paper, co-authored by Messrs. A. M. Voorhees, G. B. Sharpe, and J. T. Stegmaier, was presented, describing some of the findings (11). The sources of the data were O-D surveys and special studies. Shopping trips from a residential area were found to be proportional to ownership, but newness of residential areas, family size and age, type of residential land use, and accessibility to shopping areas were also suggested factors. Trips for "convenience goods" (groceries and drugs) were reported to be more frequent than trips for "shopping

goods" (apparel, furniture, and appliances). It was observed that shopping trips in cities under 50,000 differed from those in larger cities in that they were more frequent and had a more dispersed pattern to the CBD, they were more dependent on the CBD for convenience goods, and generally a greater percentage were made by car. It was suggested that the distribution of shopping trips be estimated, using an adaptation of Reilly's Law of Retail Gravitation, with the attraction of a shopping area being proportional to retail apparel floor area and inversely proportional to travel time from residential zones.

Mr. Harry J. Casey, Jr. (12) states that this gravitational approach is only applicable for allocation of trips for "shopping goods", those which are subject to comparative buying and therefore attract longer trips. Square feet of retail space and driving time between residential neighborhoods and retail centers are the suggested comparative factors. It is reported that market analysts often use a "watershed" analysis to determine the neighborhood attraction of stores selling foodstuffs, drug store items, hardware, and weekly needs which generally attract trips up to only five or six minutes in length. Mr. Casey observes that the gravitational approach might very well be adapted to determine street facility and parking needs of a future shopping center, to establish the "markets" for the "white-collar" workers of a residential area and the attraction of employment centers, and to measure the effect on street or highway needs of land-use changes or self-generated traffic on new facilities.

A number of researches have indicated the definite empirical

relationships between retail sales and parking space requirements. Mr. S. T. Hitchcock, who has studied parking habits for a number of years, reports that a 20-year summary of parking studies made prior to 1949 indicated that space requirements are more closely related to the volume of retail business than to any other single factor (13). With retail volumes based on "GAF"(general merchandise, apparel, and furniture) sales, it was found that the rank-size order of parking needs in 58 cities corresponded to the rank-size order of population, GAF sales, and employment in manufacturing. Estimates of parkers based on these relationships, the empirical relationship between city population and parkers per million dollars of GAF sales, and a multiple regression of 17 factors in 31 combinations, all were within 14 per cent of observed parking volumes. Mr. Hitchcock suggests that the significance of these relationships indicates that they may be applied to estimate urban travel as well as CBD parking requirements.

A method of distributing trips between zones by successive approximations has been developed by Mr. Thomas J. Fratar (14) for the purpose of estimating future travel patterns. Since growth factors such as prospective land use, population and vehicle usage trends, and prospective location and amount of employment are taken into account, the method appears more reliable than procedures based on assumptions of uniform growth. The current size of inter-zonal movement is needed, however, and accessibility is generally not accounted for. In a later paper, Mr. Fratar suggests variables which

might be used in predicting zonal volumes, and describes, using an example, the method of assigning this traffic to desire lines by successive approximations (15).

A complete traffic forecast for San Juan, based on land use anticipated in 1970 and current travel habits as found in a 1948 O-D survey, was reported by Mr. R. R. Carril of the Puerto Rico Department of Interior (16). The expansion involved factors which accounted for unequal changes in major traffic generators and adjusted to the total predicted trips. Changes expected in the current volumes generated by a zone were obtained from trends of population and estimates of the future size of business districts, industrial areas, port facilities, and other generators.

The Highway Transport Research Branch of the Bureau of Public Roads has also been investigating the usefulness of urban characteristics in obtaining trip information. Data compiled from the 1948 Washington, D.C., Metropolitan Area Transportation Study show the relation which dwelling type, ownership, income, and other economic characteristics have with trips generated in urban subdivisions. The purpose of the Bureau's current research is "to develop factors to be used in estimating changes in transportation needs as conditions change from those existing at the time of an origin and destination survey, or in making preliminary appraisal of transportation needs in an urban area in which no such analysis has been made" (17).

PROCEDURE

Traffic Survey Reports Used

In setting up an investigation procedure by which it might be possible to discover any correlations between certain characteristics of cities and their trip volumes or patterns, it was concluded that cities near or under 50,000 population, which were subjects of recent comprehensive traffic surveys, would be excellent sources of data. Three such cities in Indiana were Logansport, Richmond, and the Lafayette-West Lafayette metropolitan area. The urban area populations of these cities were, at the time of survey, in the neighborhood of 23,000, 43,000, and 53,500, respectively. All three comprehensive surveys included an internal O-D study with the data based primarily on a post card survey and expanded to conform with screenline volume checks.

Logansport, Indiana (18)

Logansport is located in north-central Indiana at the confluence of the Wabash and Eel Rivers, and is served by five federal and state highways and branch lines of two railroads. The city has about 7.5 square miles within its limits and serves as both a trade and industrial center. In order to provide data for planning of measures to relieve traffic congestion in this city the Indiana State Highway Commission authorized a comprehensive study with the Bureau

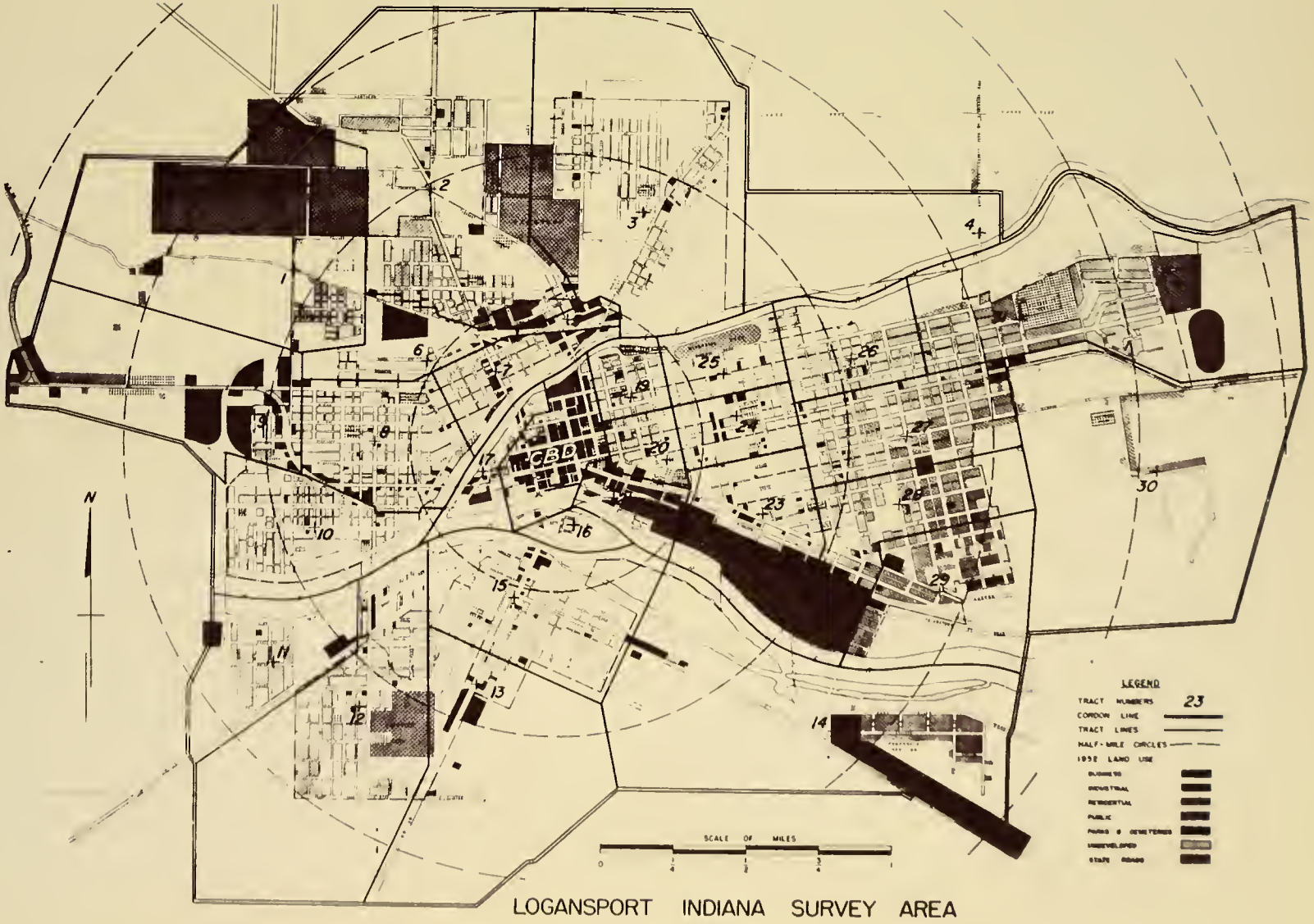
of Public Roads and the Joint Highway Research Project of Purdue University as cooperating agencies. The field data were obtained from October 8 to December 7, 1951.

The imaginary cordon line was established so as to include most urban development as well as to minimize the number of external interview stations and trip duplication. The area within this cordon was divided into 31 internal tracts for the purpose of analyzing the internal O-D data. The following criteria were used in determining tract lines:

1. Delimit central business district for parking study.
2. Delimit areas so as to be of nearly homogeneous land use.
3. Locate lines to obtain nearly square-shaped tracts with size dependent on population density.
4. Locate lines so as to facilitate ease of trip coding and screen line checking.

The cordon line and tracts as well as the land use as observed in a field inventory during the survey period, are shown on Figure 1.

The internal O-D data were collected by the controlled post card method during the month of November, 1951. A vehicle registration list complete to October 1, 1951, was used to send cards to 71.4 per cent of the 7,134 passenger car owners registered in the survey area. Of these, 2,426 usable returns were made, partly assisted by telephone calls and personal contact. Since this represented 34.0 per cent of the total registered passenger cars, the



LOGANSPORT INDIANA SURVEY AREA

FIGURE 1

trip data were considered representative of all passenger car trips. All truck owners were contacted personally.

The O-D and other trip data on these cards were coded and transferred to IBM cards for ease in tabulation. Factors based on per cent sample, codable and uncodable trips, volume counts during the survey and return periods, and screenline counts were applied to expand the data to represent all internal traffic movement on an average weekday during the survey.

During the same period of time comparable internal O-D data were collected by the home interview method. A 25 per cent sample of dwelling units was chosen geographically, and the residents questioned as to trips made on a given day. Although a comparison of the results of the two methods proved no practical differences (19), the post card data showed greater completeness and was used in the final analysis.

Richmond, Indiana (20)

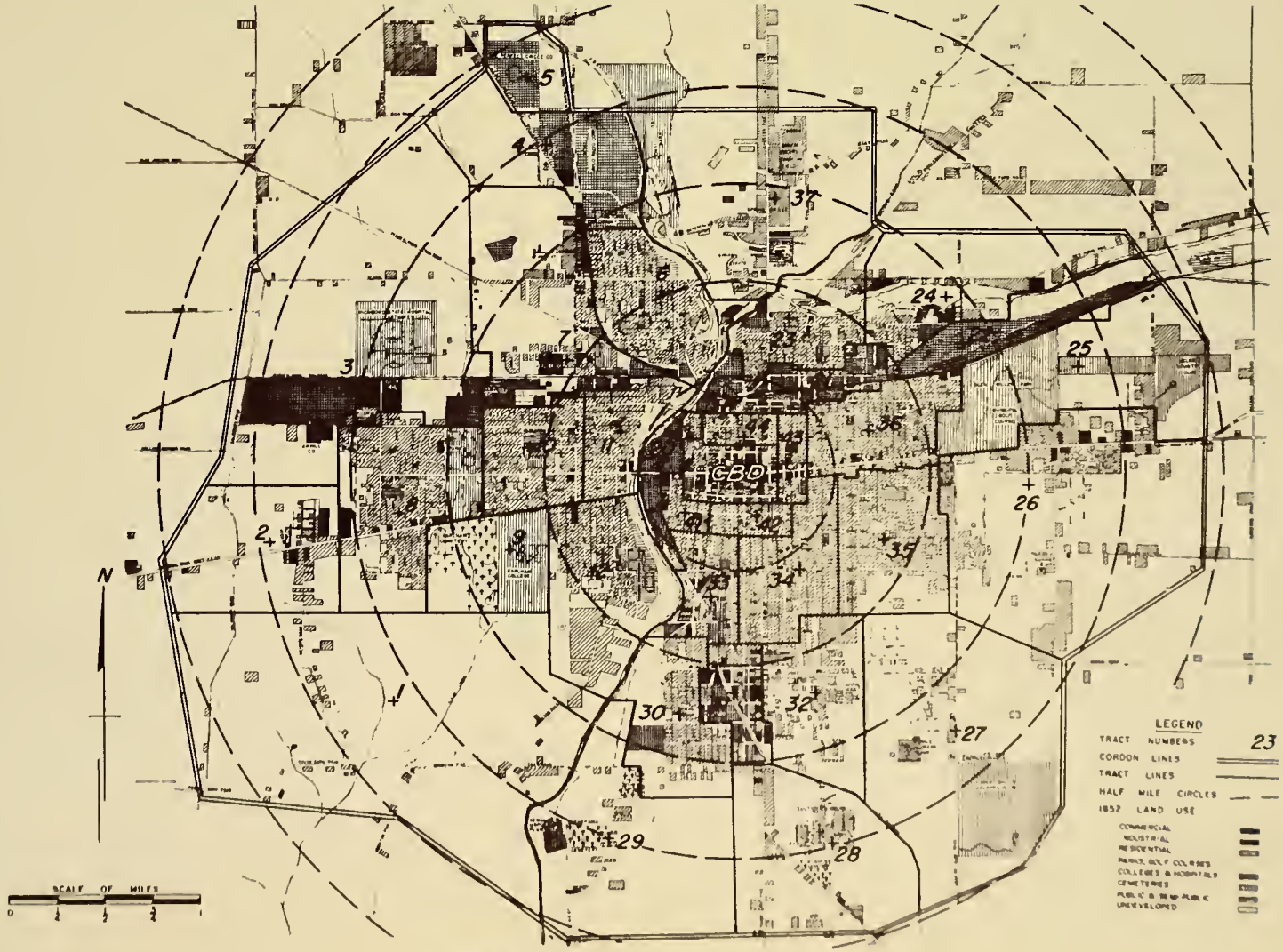
Richmond is situated near the east-central edge of Indiana and is served by six state and federal highways, including U.S. 40, "the National Road". Transportation is also provided by a small municipal airport and two main line railroads, and the city has direct connection with Indianapolis, Cincinnati, Columbus, and Dayton. The city is known for its many industries which employ over 15,000 workers. The commercial district serves an estimated 250,000 people in nearby Indiana and Ohio counties.

In order to obtain facts on which to base recommendations for

relieving traffic congestion the Indiana State Highway Commission authorized a comprehensive traffic survey. Again, the Bureau of Public Roads and the Purdue Joint Highway Research Project were cooperating agencies. The field data were collected during the months of June and July, 1952.

The cordon line enclosing the survey area was established using criteria similar to those used for the Logansport cordon. This area was divided into 37 tracts with tracts 1 through 12 west of the river screenline and 20 through 37 east of that line. Tracts 50 through 52 contain the central business district, and tracts 41 through 44 were designated as "parking overflow" zones for the purposes of the parking study. The tracts were delimited using criteria similar to those used in Logansport, the principal one being the inclusion of only one major land use area within a tract. The land use as determined by field inventory, the tracts, and cordon line are shown on Figure 2.

Following the controlled post card procedure in obtaining the internal O-D data, cards were mailed to all persons with Richmond or rural route addresses who had vehicles registered as of June 5. Trip information for each vehicle during a specified 24-hour period was requested of 14,426 passenger car and 1,408 truck registrants. In addition, fleet owners and registrants of other vehicle types were contacted personally. Between June 16 and July 15, a total of 4,872 cards were returned with usable information. This represented 30.8 per cent of the cards sent.



RICHMOND INDIANA SURVEY AREA

FIGURE 2

The coded information on reported internal trips was transferred to IBM cards and expansion factors applied to sample groups based on vehicle type and tract of address. These factors accounted for the total registrants and usable returns, the number of codable and uncodable trips, the traffic volumes during return period and survey period, the number of new registrations during the survey period, and, finally, the adjustment necessary to approximate screen-line completeness. The resulting tabulated trip data represent all internal trips on an average weekday during the survey period, June 10 to July 3, 1952.

Lafayette-West Lafayette, Indiana (21)

Lafayette, Indiana, is also an important industrial and trade center and is located in the west-central part of Indiana. The adjacent city across the Wabash River is West Lafayette, the home of Purdue University. The 1950 Census of Population indicated that the West Lafayette population is about one-third that of Lafayette and that the total urban population was about 47,441. The area is served by seven state and federal routes, four railroads, and a commercial airport, and it lies on the heavily travelled route between Indianapolis and Chicago. A comprehensive traffic survey was authorized by the Indiana State Highway Commission with the Bureau of Public Roads as cooperating agency, and the field data were collected between September 9, 1952 and May 1, 1953.

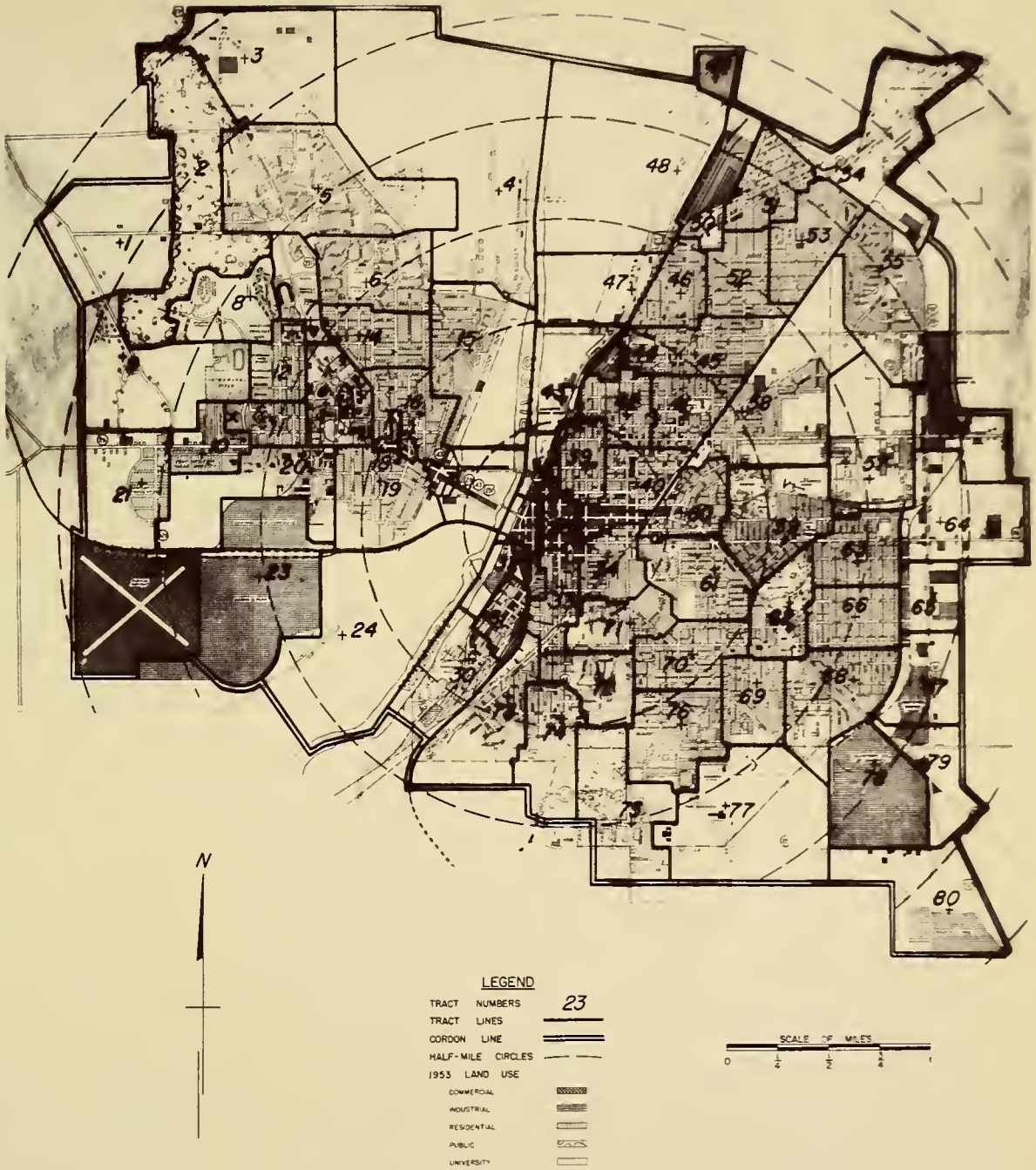
Because of the proximity of the two cities and their common areas of influence, both were necessarily enclosed by the cordon.

This survey area was divided into 75 tracts, 24 west of the river screenline and 51 to the east. The criteria used in delimiting the tracts were similar to those used in the Logansport and Richmond areas. Tracts 35, 36, and 37 enclose the main business district. The 1953 land use, the internal tracts, and the cordon enclosing the Lafayette-West Lafayette survey area are shown on Figure 3.

The internal O-D data were collected by the controlled post card method for the most part. Using a registration list which included university registered vehicles, cards were mailed to 21,058 registrants and 41.3 per cent were returned usable. The 736 personal interviews yielded 81.8 per cent usable trip reports. Because of disagreement with the screenline counts a supplemental 5 per cent home interview sample was used to adjust passenger car trip data. The data were expanded using factors similar to those used for the Logansport and Richmond data and the resulting tabulations represent internal trips on an average weekday during the survey period.

Obtaining the Data

After gathering all pertinent information from these survey files and reports and preparing some additional summaries, the next step was the collection of data not obtained as a part of the surveys. This presented a problem at times, because in order to be completely compatible with the trip data, all information obtained had to be as of the dates of the O-D surveys. Although this was not entirely possible for some of the data, most of the information was dated within three months of the survey period.



LAFAYETTE - WEST LAFAYETTE SURVEY AREA

FIGURE 3

A list of desired data was made up. Careful examination of the previously mentioned papers and reports of related investigations, as well as personal contact and correspondence with a number of persons familiar with the measurement of economic, population, and physical urban characteristics, resulted in a very complete list of items having potential value to this study. Although it was not expected that all of these would be obtainable, nor that once obtained they would all contribute to the results, efforts were made to at least examine the availability of each. These suggested characteristics are listed and discussed as to pertinence and source of data as follows:

1. Population of the study area, survey tracts, land use zones, and half-mile wide rings concentric about the central business district.

   Population was the characteristic most mentioned by the references consulted and has been proven numerous times to have a direct relation to trip generation. Possible sources suggested were state and U.S. bureaus of census enumeration values, population density maps, city directories and Sanborn maps, and water and telephone installation information. It was found that the census courts, distributed according to dwelling distribution, produced the best population estimates for this study.

2. Number of dwelling units in each tract or land use zone and an economic classification of housing.

Trips per dwelling have been used as units of measuring the rate of generation of residential zones, and there is some evidence that this rate varies with the type of dwelling. Sanborn and land use maps and city directories were considered the best sources for this study, but a field inventory would probably be best for a study of current conditions. Particular accuracy in locating dwellings is desirable here, since, in this study at least, dwelling distribution was the basis for translating population by census enumeration districts into tract or ring populations.

3. Income per capita or per dwelling in each survey tract or land use zone.

A number of previous investigations have shown that economy, measured in some such average units, is related to trip generation. Per-capita and per-dwelling rates have been suggested for measuring economy of residential zones. This information was found not to be available by census districts for most cities under 50,000 population, and other measures of economy were substituted for this study.

4. Number of vehicles or passenger cars registered in each tract or residential zone.

Vehicle ownership, measured in vehicles per capita or persons per car, is a popular indicator of economy, particularly as related to the generation of vehicular trips. Registration lists showing the address of each vehicle registrant are generally

available from various state registration agencies. Tract summaries for the three survey areas used in this study were made at the time of the surveys.

5. Total employment in each tract or in each commercial and industrial land use zone.

Previous studies have indicated that employment is the characteristic of an industrial area most related to the volume of trips it generates. It was also considered probable that the number of persons employed in other land use tracts affects their volume of generated trips. Potential sources of employment data are censuses and special business studies and records kept by chambers of commerce, employment security offices, or other similar agencies. The Indiana Employment Security Division was found to have the most complete information on Indiana cities, but a compilation of records of employment in individual small businesses did not appear to exist.

6. Floor space of drug, food, apparel, furniture, or all retail stores by tract or for the central business district.

These values have been used to measure retail business which is closely related to trips generated by commercial areas. No sources were found which provided floor space data to the extent that it could be assigned to the survey tracts or central business districts of the studied cities.

7. Number or amount of retail sales, particularly drug, food, apparel, and furniture sales, by tract or in the central business district.

Difficulty was also experienced in obtaining sales information by store or location. For a study of the relationship of sales with current trip generation, questionnaire or personal contact with individual large stores and with a sample of the smaller stores would be likely to provide the best data.

8. Number of daily customers to stores and restaurants, and the number of daily visitors to museums, bowling alleys, theaters, parks, and other special trip generators.

These figures would undoubtedly aid in estimating the daily trips to and from special locations. Where current information is needed, it would be best provided by direct contact with the managers or proprietors or by special volume counts.

9. Acreage of each land use space, listed by land use classification and survey tract. Several previous studies have summarized origin-destination information in terms of trips per acre of various land use types. For the purposes of this investigation the land use classifications were patterned after those most used in other studies and were defined broadly as residential, institutional, industrial, commercial, and the central business district. This classification was found to be in sufficient accordance with land use maps prepared during the three surveys to allow the scaling of land use acreages directly from them.

Because of the large amount of undeveloped land in fringe tracts,

that acreage was not assigned to the above types.

10. Straight line and over-the-road distances and travel times between tracts and from the CBD to all tracts.

The spatial relationship of pairs of tracts has been shown to have some influence on the rate at which they exchange trips. The distances were scaled from large street and tract maps of the areas studied. Over-the-road distances were measured along the most direct routes over streets existing at the time of survey. These values were used in lieu of travel times which were not obtained during the surveys except on a few primary streets.

Investigations and Application

In the course of studying the results of previous investigations a number of tables, regression lines, and other indications of characteristic-trip relationships were extracted. Investigations were then made of all such relationships which could be observed using the available measurements and O-D data of the Logansport and Richmond, Indiana survey areas.

In setting up the tables of data from which the scatter diagrams are plotted, several additional correlation possibilities became evident. and these also were investigated. Where the data were comparable, results of other studies have been shown, although most of these were derived from larger urban areas.

The primary objective of each of the investigations was to show by some means, such as scatter diagrams, the general amount of correlation appearing to exist between the examined variables, and to evaluate

certain factors influencing trip generation or exchange. Since nearly all the variables contain estimated values, the accuracies of which can only be postulated, no attempts were made to accurately measure amounts of correlation. Preliminary regression lines were fit by freehand to some of the data to test them for present usefulness. It was expected that close examination of the data and analysis of its discrepancies from apparent lines of regression might reveal clues indicating the potential values of each characteristic and relationship.

The relationships or factors which appeared to have the least immediate value were "weeded-out", leaving only those which were observed to show the highest correlation or to produce the best trip estimates for the Logansport and Richmond urban areas. These were then used to estimate a limited number of trip volumes and movements in the Lafayette-West Lafayette survey area. Finally, a comparison of the estimated values with those found in the O-D survey of that area was made in order to indicate the adequacy of empirical trip-estimating techniques in their present stage of development.

INVESTIGATION OF CORRELATIONS

A problem immediately encountered in the investigation of empirical relationships observed in previous studies was that of reconciling the Logansport and Richmond data so as to enable comparison with the data from the other sources. Due to certain differences in definitions of measured characteristics or trip values, direct comparisons were not always possible. However, in order to give some indication of the feasibility and practicability of some of the correlations, an indirect procedure for arriving at comparable figures was sometimes employed.

In determining a method of classifying the investigations for convenience in performance and reporting, the most logical groupings appeared to be those which probably would be encountered in sequence in a complete analysis of internal trips. The classifications were then based on connection with the estimation of total internal trips, total trips generated by different types of tracts. trips between different types of tract pairs, and trips distributed from one tract to all others.

Total Trips

It is not expected that the total number of trips which are made within an area will be of immediate or direct use in the determination of the pattern of those trips. But a knowledge of this value will aid in obtaining a concept of the general magnitude of traffic in an urban area.

Survey Area Population

In order to examine the applicability of certain curves relating trips to population, good estimates of the total populations of the survey areas were required. A matter of no little concern is that of obtaining an accurate estimate. If the cordon should happen to coincide with the city limits, then a U.S. Bureau of Census estimate would provide this figure. Most survey cordon lines are chosen so as to include all areas of land use which might affect the travel pattern of the city, and therefore, they would be likely not to coincide with the city limits,and generally lie outside of it. Some method must be used to obtain an estimate to include that area between city limits and the cordon.

From the experience of making such estimates for the three study areas it is recommended that they be based on a recent Bureau of Census estimate enlarged by a field count of dwelling units by census district and by survey tract, and between the city limits and the cordon. The enumeration district maps and population and housing machine sheets for any city can be made available by the Geography Division of the Bureau of the Census. The person-per-dwelling unit factor is important here, and a 25 per cent home interview sample showed this value to be 3.40 for the fringe zone between the Logansport limits and cordon.

As a check on the reliability of this figure an estimate of the Logansport survey area population was made using 1950 census values by census ward, apparent proportions of the residential area in each survey tract by ward and fringe zone, and a field count of dwelling

units by tracts. The area proportions were assumed to equal the dwelling unit proportions. Persons-per-dwelling unit factors were obtained from the 20 per cent home interview sample for the ward dwellings and 3.40 was used for all dwellings outside the wards (and city limits) but inside the cordon. The area population was estimated to be 23,346. The area population estimated from the 20 per cent sample of all dwellings was 23,345. A third method based entirely on apparent residential area proportions and the ward census resulted in an estimate of 23,344. While the first and third methods showed only fair agreement with the sample values at the tract population level, all three resulted in remarkably agreeable estimates of the population of the survey area. The 95 per cent confidence interval attached to the sample estimate was 1,267. The 3.40 value was further substantiated by calculation of the person-per-dwelling unit factor for census enumeration districts surrounding the city limits of Richmond, Lafayette and West Lafayette.

Total Internal Trips

There are a number of indications that the total population of an urban area is directly proportional to the total internal trips generated by that area. A preliminary study at the Yale Bureau of Highway Traffic showed this to be true, but, that the correlation is imperfect (1). However, of the twenty home-interview O-D surveys chosen for this study, only two were for cities under 50 000 population. It remains to be determined exactly how useful the area population of a small city (under 50,000) is in trip estimations.

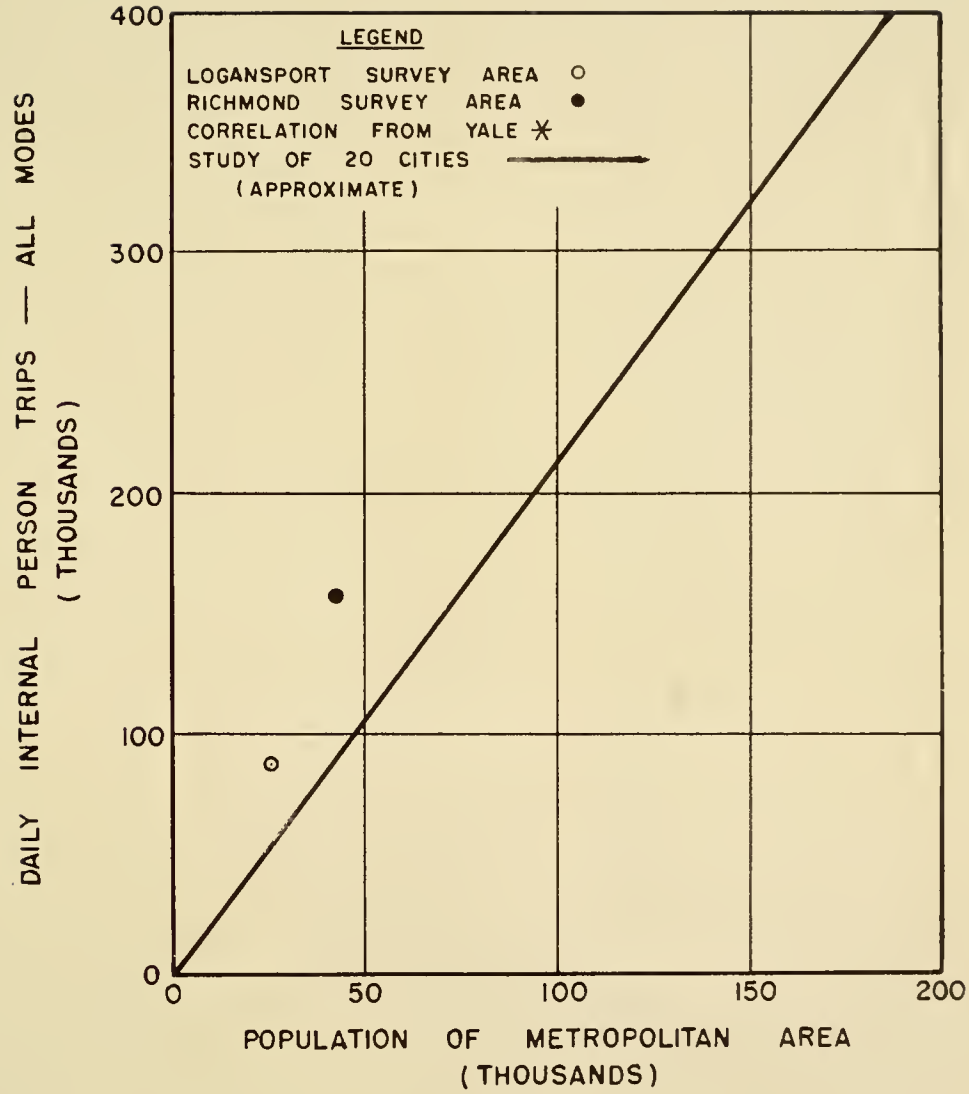
Using the sample estimate of the Logansport survey area population of 23,345 and a census-dwelling estimate of 43,000 for the Richmond survey area, estimates of total internal person trips by all modes of travel for an average weekday were possible using the relationship developed in the Yale study. This relationship is depicted in Figure 4 which shows that for these populations the person trip estimates are about 50,000 and 90,000, respectively. The internal vehicular trips reported in the survey results are as follows:

Vehicle Trips

	Logansport	Richmond
Passenger car trips	47,197	82,233
Truck trips	6,400	14,608
Total	53,597	96,841

These values are not readily comparable with the 50,000 and 90,000 estimates, since those estimates represent person trips while the trips shown above are vehicle trips. Person trips are, of course, always greater in number than vehicle trips.

An average value of persons per vehicle is needed to go from vehicle trips to person trips or vice versa. The Logansport survey report includes an analysis of persons per passenger car for through and local trips, and the Richmond study included a similar summary for external passenger car trips by purpose. These summaries are shown in Table 1. From these figures, it can be said that there are fewer



* SOURCE : WYNN, F. H., "INTRA-CITY TRAFFIC MOVEMENTS", HRB, 1955

CORRELATION OF TRIPS AND AREA POPULATIONS

FIGURE 4

Table 1

Persons Per Passenger Car

Type of Trip	Purpose	Logansport Traffic Survey[1] Average Number of Persons/Pass. car	Percentage of all Ext.[2] Pass.Car Trips
Thru (Ext.-Ext.)	Work	1.89	12.5
"	Other	2.61	6.7
"	All	2.14	19.2
Local (Int.-Ext.)	Work	1.68	58.2
"	Other	2.29	22.6
"	All	1.85	80.8
External	Work	1.72	70.7
"	Other	2.36	29.3
" (2)	All	1.91	100.0

Type of Trip	Purpose	Richmond Traffic Survey[3] Average Number of Persons/Pass.car	Percentage of all Ext.[2] Pass. Car Trips
External	Work	1.59	31.2
"	Business	1.88	23.2
"	Medical	2.21	1.7
"	Shopping	2.46	5.5
"	Soc. and Rec.	2.78	33.9
"	Serve Pass.	2.49	2.3
"	Eat Meal	2.39	2.1
"	Change Mode	3.07	0.0
"	Other	2.43	0.1
"	Not obtained	2.28	0.0
" (4)	All	2.16	100.0

Notes:

(1) Source: Logansport: Indiana Traffic Survey Report, 1952.
(2) 15,695 ext.pass.car trips = 79.0 per cent of 19,874 total external trips.
(3) Source: Richmond, Indiana Traffic Survey Report, 1952.
(4) 32,093 ext.pass.car trips = 83.0 per cent of 38,683 total external trips.

persons in cars travelling for work than for other purposes and that local trips (those with either origin or destination inside the survey area) are composed of a higher percentage of work trips than are through trips. Assuming that the passenger-per-car factors are 1.7 for work trips and 2.3 for trips having other purposes, the following is an estimate of total internal person trips in that survey area:

Logansport

Mode	Vehicle Trips			Person Trips		
	Total	Work	Other	Work	Other	Total
Passenger car	47197	39645	7552	62297	17370	79667
Truck	6400	6400	0	6400	0	6400
Bus	-	-	-	-	-	2050
						88117

Since Richmond internal data included no information on trip passengers or purposes, person trips could only be estimated by assuming the same ratio of person trips to vehicle trips estimated for the Logansport data. This ratio is 1.64 and the estimate of internal person trips is 159,000.

The relative amounts of discrepancy of these two estimates from the line developed from other data can be observed in Figure 4. Since some discrepancy would exist even if the estimates were based on a factor of 1.00 persons per vehicle, other causes must also exist.

These may lie in possible differences between the areas within the Logansport and Richmond cordons and those of the 20 cities producing the regression, or they may be simply due to imperfection of correlation in the range of small cities. At any rate, the discrepancy of the Logansport and Richmond person trip estimates from the regression from other data does not disprove the existence of some relationship between area population and total trips. It will be shown later that the total car trips in the Lafayette area was predictable from such existing relationships in the Logansport and Richmond data.

Total Work Trips

The aforementioned investigations at Yale disclosed that trips for the purpose of going to or from work are more consistently related to the city size than is the total volume of internal trips. This was attributed to the facts that work trips are generally more completely reported, they constitute the largest category of trips by purpose, and the labor force is generally about 40 per cent of the urban population and is distributed similarly (22).

While the reported relationship between population and total work trips enable work trip estimates of about 6,000 and 19.000 for the Logansport and Richmond areas, no comparable figures were available. Purpose information was not obtained in the Richmond post card O-D study, and the "work" trip category of the Logansport survey included all except non-essential trips.

It appears very likely, however, that trips to or from working areas are related to population. It will be seen that this relation-

ship carries over to the tract level and is reflected in important residential-industrial tract movements.

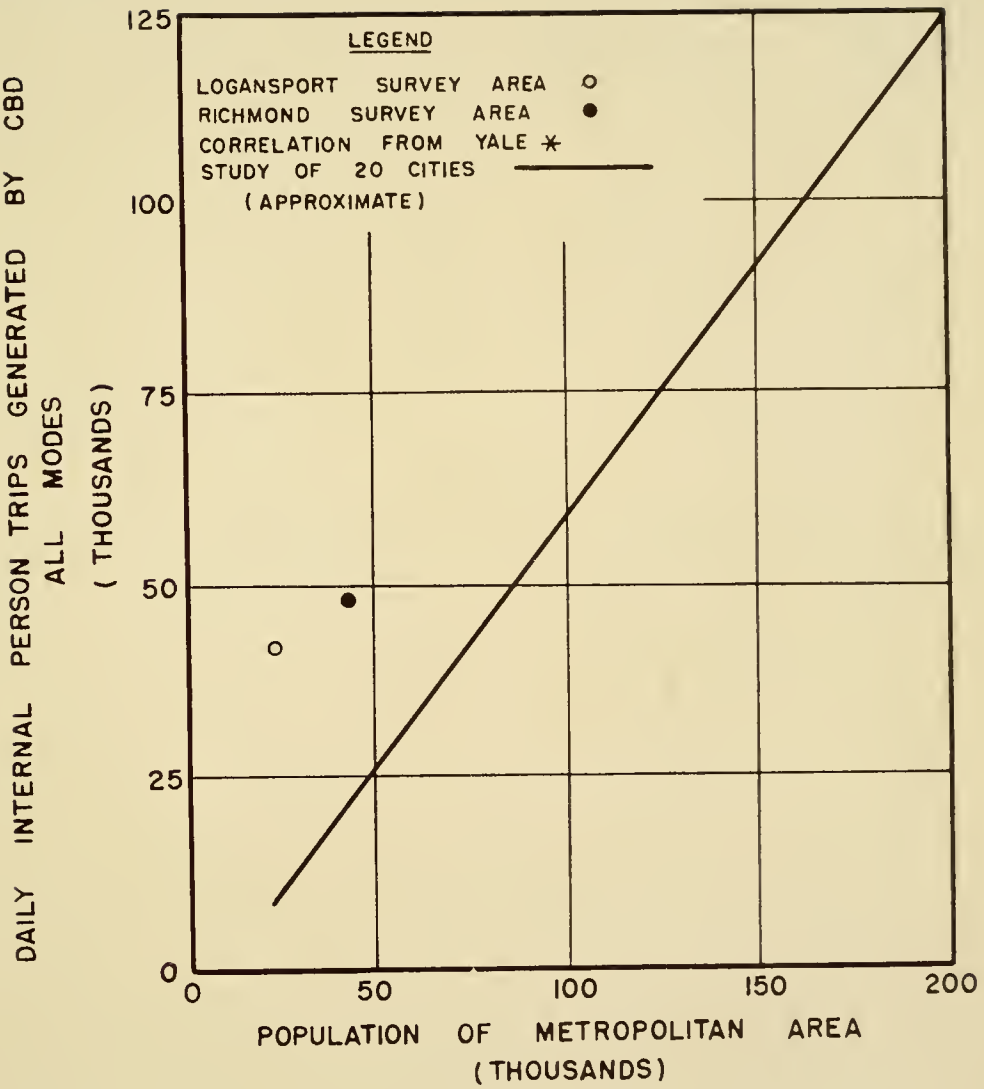
Tract Trips

In the general consideration of why people travel where they do within a city it would seem logical that knowledge of the volume of daily trips generated by the various parts of the city would be the first requirement in the determination of the pattern which those trips take in satisfying their purposes. The term "generated trips" is used in this study to refer to average weekday trips into and out of an area. Since the object was to study those trips which do not cross a cordon, internal trips only are discussed.

Central Business District Trips

The central business district of CBD is defined as the "core" or center of a city's main business area "of compact and reasonably symmetrical shape in which most blocks are destinations of more auto driver space-hour demand than the parking spaces in the block can accommodate" (1). The CBD has been shown repeatedly to generate a preponderant number of trips by all modes of travel.

The Yale study has indicated a definite correlation between CBD generated trip volume and city size for a group of 20 cities ranging up to 600,000 in population. A portion of this line of correlation is shown in Figure 5. From this relationship it may be expected that in Logansport CBD-generated trips would be in the neighborhood of 8,500, while in a city the size of Richmond the CBD would generate about 22,000 daily person trips by all modes of travel.



* SOURCE : WYNN, F. H., "INTRA-CITY TRAFFIC MOVEMENTS", HRB, 1955

CORRELATION OF CBD TRIPS AND AREA POPULATIONS

FIGURE 5

From the survey data the following estimates of person trips generated by the central business district can be made:

Logansport

Mode	Vehicle Trips	Assumed Persons per Vehicle	Estimated Person Trips
Passenger car	21889	1.8	39400
Truck	3560	1.0	3560
Bus	-	-	1230
			44190

Richmond

Mode	Vehicle Trips	Assumed Persons per Vehicle	Estimated Person Trips
Passenger car	23473	1.8	42200
Truck	4468	1.0	4468
Bus	-	-	2000
			48668

These estimates are several times as large as the values expected, and the plotted points on Figure 5 lie considerably above the line of correlation. A small portion of this discrepancy may be explained by error in the estimated person trips. It is certain, therefore, that other causes of the discrepancy are present. Errors in survey values or in the regression may explain part of it. It is also

considered very possible that, while they conform with the general definition of central business districts, the Logansport and Richmond CBD's may differ enough from those of the other 20 cities that the CBD trip values are not strictly comparable. If this is true, then it clearly demonstrates the need for precise control of tract definition and delimitation when relationships are desired which may be applied to other locations.

Residential Tract Trips

Since less trips are generated by tracts beyond the CBD, there are less data available and more difficulty in obtaining trip estimates.

It has been established by previous studies that the population of a metropolitan area is strongly related to generated trips if not always a good estimator by itself. It would seem to follow, using the same logic, that the greater the population of a residential portion of a city, the greater will be the number of trips it generates. If one desires to estimate the trips generated by a residential tract, an estimate of its population appears necessary.

Inasmuch as survey tracts do not coincide with census tracts, the obtaining of a reliable value for the population of a survey tract is a difficult problem.

The best information on which to base population estimates for the Logansport survey tracts was the 1950 Census of Population by wards and data obtained in a 25 per cent home interview sample. The survey data include the number of persons per dwelling unit as well as the number of dwelling units by tract at the time of survey.

An accurate population estimate was therefore possible for each tract.

Two alternate methods of estimating Logansport tract populations were also used for comparative purposes. The first, based entirely on estimated portions of residential land in survey tracts and Census wards, resulted in tract populations considerably in error. A second procedure, based on dwelling counts by tracts and wards, the known number of tract dwelling units, and values of persons per dwelling estimated from survey data, resulted in much better tract population estimates. It was observed that there was a tendency for these estimates to be high in tracts where dwellings are more expensive and have larger lots, and low in zones of older or multi-family dwellings. There were indications that in areas having less variable types and densities of dwellings, the populations are roughly proportional to acreages of residential land use.

During the Richmond Survey no data were obtained on dwelling units or persons in a tract. The best information on which to base tract population estimates was that taken from Sanborn Maps corrected to 1950, a 1952 land use map, and the 1950 Census population and dwelling unit count sheets. Since the survey was made within two years of the census, it was not considered essential to make adjustments to the 1950 figures in addition to those resulting from indications of fringe development observed during the land use field check. The tract counts of dwellings, apartments, and flats taken from the Sanborn Maps were generally lower than comparable census counts, particularly near the CBD where store buildings with dwellings on

the upper floors are more frequent. The information was expanded to conform with census dwelling counts and thereby served to distribute the population counts within the enumeration districts.

It is felt that this is a reliable method for estimating tract populations. Although in this case it was impossible to make a field check of the dwellings as they were in 1952, it is recommended that this be done when current estimates are needed in order to more properly adjust for changes since census enumeration.

It should be noted that nearly all geographical survey tracts have more than one land use. The effect of population on trip generation would be expected to be more direct where the area in "pure" residential use considerably exceeds that used for commercial, industrial, or institutional purposes.

Further modifications might be indicated by certain economic indices such as vehicles per capita, income per capita, persons per dwelling, and types of dwellings. The effect of distance from the central business district has also been suggested as being correlated with residential tract trips.

In order to discover whether or not population alone has value in estimating tract trips, population and trip data were collected for 35 residential tracts in Logansport and Richmond. Only tracts predominantly residential in nature were selected, and those residential tracts with important businesses or large areas of undeveloped land were omitted. This was done to obtain a group of nearly "pure" residential tracts and thereby reduce the effects of business attraction or lack of residential attraction.

Data for these tracts are shown in Table 2 and graphically on Figure 6. The strong influence of population on car trip generation in these selected tracts is clearly indicated. As would be expected, the correlation is not 100 per cent, and there is much that population alone does not explain. But the scatter diagram itself is strong evidence that the population of a tract cannot be ignored in developing a means of estimating generated trips.

One of the most fruitful sources of experimental information on trips generated by residential tracts is the Detroit Metropolitan Area Traffic Study. Relationships have been shown to exist between trips generated in 254 residential zones and car registration, distance from CBD, and number of dwelling units (6).

In order to discover whether similar correlations exist in the Logansport and Richmond data, the pertinent information was first compiled as shown in Tables 3 and 4. Only tracts predominantly residential in nature were used for this investigation.

Reasonably accurate estimates of total tract dwelling units were obtained from a field inventory taken at the time of the Logansport survey, and from Sanborn maps, census counts, and a land use map of Richmond. The number of passenger cars registered in each tract was obtained from summaries of official county registration lists prepared during the surveys. The straight line distances from the CBD to each selected tract are mileages scaled from large city maps and are measured between tract "centers of gravity", or estimated points of highest land use concentration. Acreage in residential land use was measured on large scale land use tract maps, the data

Table 2

Logansport and Richmond Population-Trip Data

Logansport			Richmond		
Res.[1] Tract No.	Est.[2] Tract Popula-tion	Int.Pass.[3] Car Trips	Res.[1] Tract No.	Est.[2] Tract Popula-tion	Int.Pass.[3] Car Trips
3	955	2985	2	204	390
8	2060	5245	6	3581	7013
10	1400	2878	10	2280	7821
11	267	436	11	2219	6337
12	1018	1816	12	1816	5018
13	354	1262	23	2647	3645
14	249	387	24	1014	1360
15	1452	4244	26	1057	3755
16	106	229	27	228	1211
17	370	1285	28	622	1356
19	854	2158	30	1558	2908
20	487	3451	32	965	2368
23	1662	3489	33	1740	5895
25	955	2450	34	4315	9737
26	1372	3646	35	2170	6037
27	1389	4803	36	5001	12241
28	955	2113	37	751	4727
29	431	1038			

Notes:

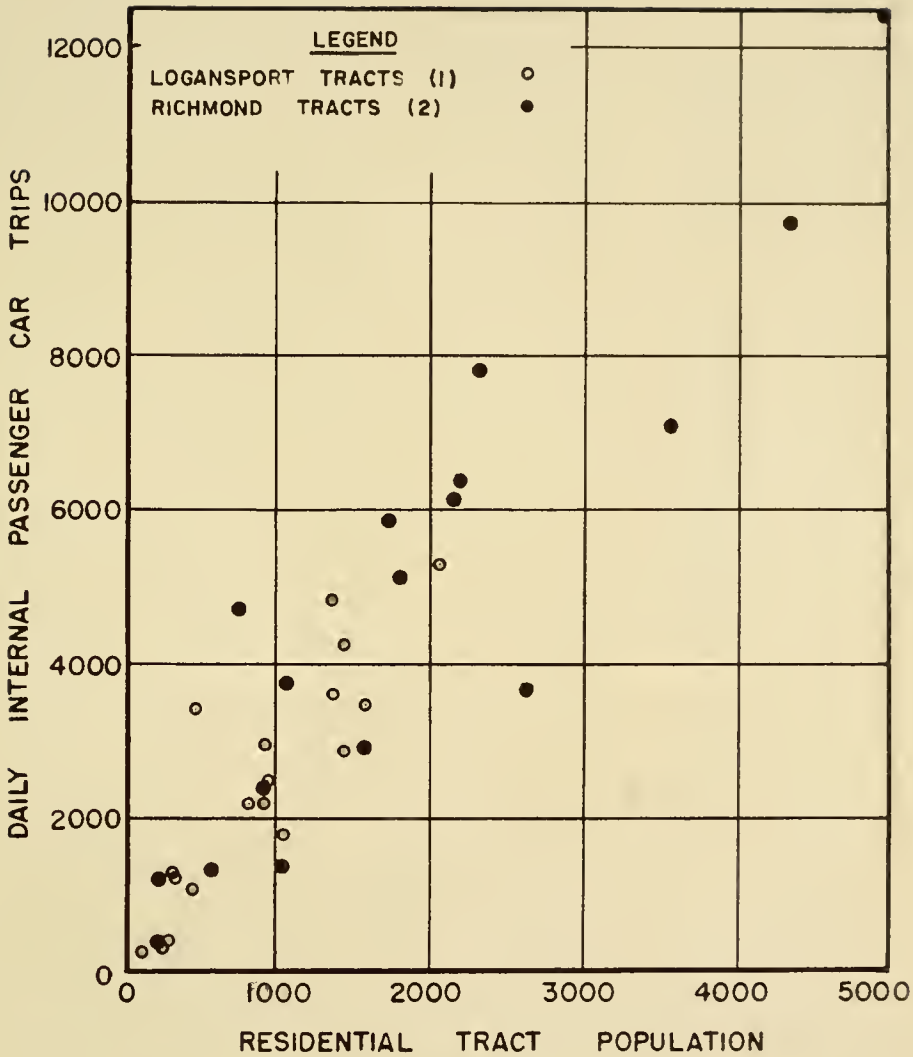
1. Selected residential tracts

2. Estimated from home interview data.

3. Internal passenger car trips; Source: Logansport, Indiana Traffic survey report.

4. Estimated from dwelling unit and census data

5. Source: Richmond, Indiana traffic survey report.



NOTES :

(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY

CORRELATION OF CAR TRIPS
AND RESIDENTIAL TRACT POPULATION

FIGURE 6

Table 3

Logansport Residential Tract Data

Res. Tract No.[1]	No. Dwg. Units[2]	No. Pass. Cars[3]	Cars Per Dwg.	Mi. From CBD[4]	Res. Acres[5]	Dwg. Units per Res. Acre	Int. Car Trips[6]	Int. Trips per Dwg.
3	306	324	1.06	0.80	71	4.3	2985	9.8
8	672	643	0.96	0.65	64	10.5	5245	7.8
10	402	382	0.95	0.85	46	8.7	2878	7.2
11	81	74	0.91	1.20	23	3.5	436	5.4
12	300	270	0.90	1.10	61	4.9	1816	6.1
13	111	119	1.07	0.85	18	6.2	1262	11.4
14	61	44	0.72	1.30	25	2.4	387	6.3
15	462	459	0.99	0.55	54	8.6	4244	9.2
16	32	34	1.06	0.30	5	6.4	229	7.2
17	122	101	0.83	0.30	8	15.3	1285	10.5
19	261	227	0.87	0.30	19	13.7	2158	8.3
20	142	148	1.04	0.40	16	8.9	3451	24.3
23	463	373	0.81	0.70	45	10.3	3489	7.5
25	307	313	1.02	0.60	28	11.0	2450	8.0
26	437	413	0.95	1.00	47	9.3	3646	8.3
27	423	499	1.18	1.20	75	5.6	4803	11.4
28	258	269	1.04	1.20	39	6.6	2113	8.2
29	135	123	0.91	1.40	32	4.2	1038	7.7

Notes:

1. Selected survey tracts of predominantly residential land use.

2. Source: Survey summary of 1951 field inventory of dwelling units.

3. Source: Survey summary of official 1951 registration lists.

4. Source: Survey summary of scaled straight line distances between tract centers of gravity.

5. Scaled from 1952 land use map.

6. Source: 1952 survey summary of average weekday internal passenger car trips; data expanded from post card sample to 100 per cent screenline check.

Table 4

Richmond Residential Tract Data

Res.[1] Tract No.	No.[2] Dwg. Units	No.[3] Pass. Cars	Cars Per Dwg.	Mi.[4] from CBD	Res.[5] Acres	Dwg. Units per Res. Acre	Int.[6] Car Trips	Int.Car Trips per Dwg.
2	60	36	0.60	2.44	10	6.0	390	6.5
6	1067	910	0.85	1.04	130	8.2	7013	6.6
10	737	746	1.01	1.07	82	9.0	7821	10.6
11	704	654	0.93	0.63	57	12.4	6337	9.0
12	578	591	1.02	0.81	88	6.6	5018	8.7
23	666	508	0.76	0.85	65	10.2	3645	5.5
24	259	193	0.75	1.41	40	6.5	1360	5.3
26	354	298	0.84	1.48	100	3.5	3755	10.6
27	67	86	1.28	1.74	21	3.2	1211	18.1
28	183	153	0.84	2.02	40	4.6	1356	7.4
30	444	404	0.91	1.28	69	6.4	2908	6.5
32	283	253	0.89	1.22	80	3.5	2368	8.4
33	539	512	0.95	0.62	37	14.6	5895	10.9
34	1418	1160	0.82	0.59	136	10.4	9737	6.9
35	764	756	0.99	0.83	140	5.5	6037	7.9
36	1595	1366	0.86	0.70	125	12.8	12241	7.7
37	221	245	1.11	1.47	100	2.2	4727	21.4

Notes:

1. Selected survey tracts of predominantly residential land use.

2. Sources: Sanborn maps corrected to 1950, 1952 land use map, and 1950 census of housing.

3. Source: Survey summary of official 1952 registration lists.

4. Scaled straight line distance between tract centers of gravity.

5. Scaled from 1952 land use map.

6. Source: 1952 survey summary of average weekday internal sample to 100 per cent screenline check.

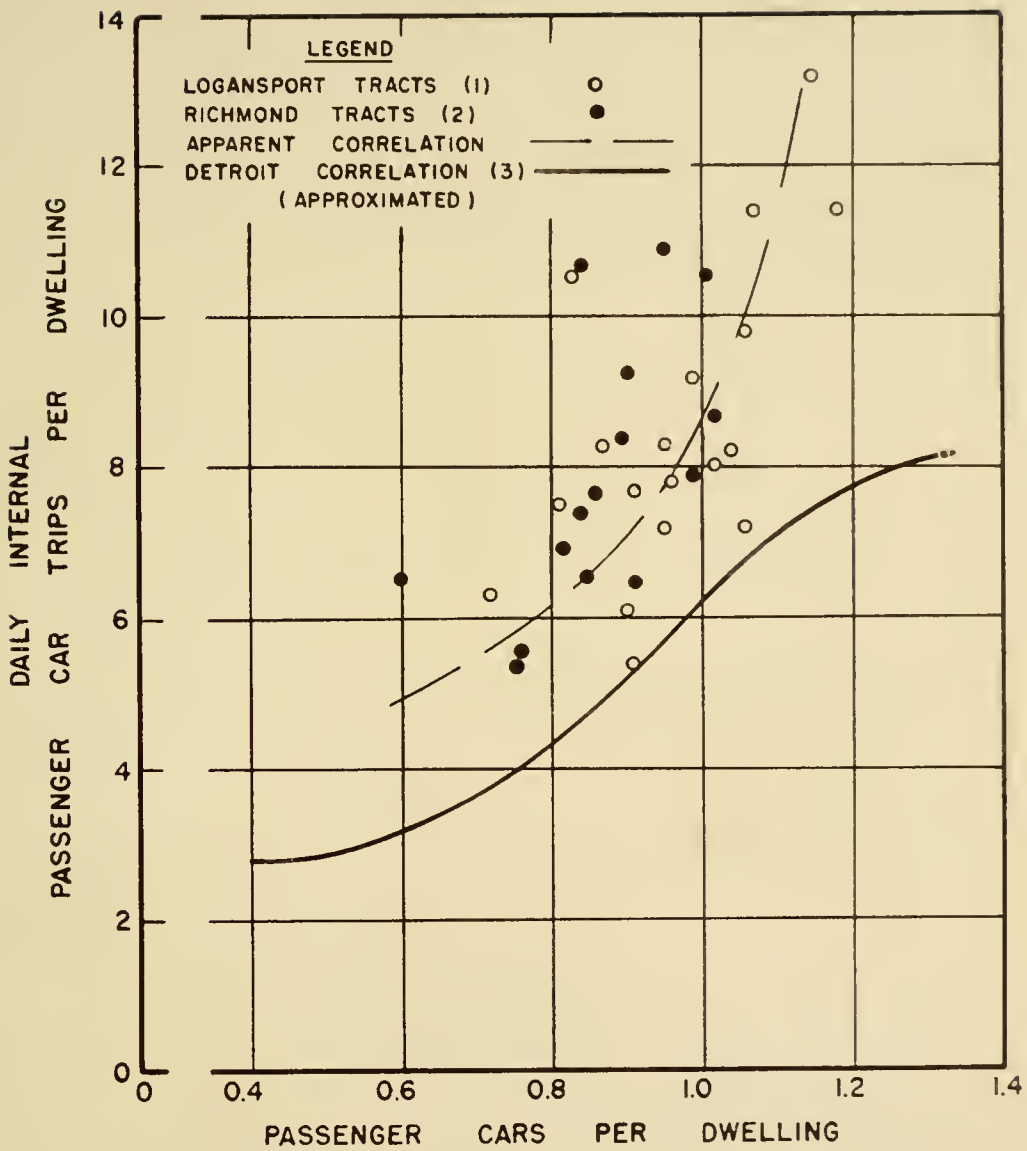
being obtained through field inventories at the time of survey in both cities. The values of internal passenger car trips to and from each selected tract were taken from the O-D charts of the survey reports and were in both cities based on a post card sample and expanded to a 100 per cent screenline check.

Plotting tract daily passenger car trips per dwelling vs. cars per dwelling for both sets of data (Figure 7) indicates that the correlation shown by tracts in Detroit does not hold true for those in Richmond and Logansport. However, there does appear to be some correlation, with the number of trips per dwelling increasing at an increasing rate from about 5.5 at 0.7 cars per dwelling to about 11.5 at 1.1.

This suggests that in these two cities more car trips can be expected to be generated by residential zones in which there are more cars per dwelling than in those where a large number of homes are without cars.

Trips per dwelling for residential tracts in the two cities were also plotted against dwelling units per residential acre (Figure 8) and distance from the CBD (Figure 9). In neither case does there appear to be any correlation nor does it seem possible that the data could be related as they were in Detroit.

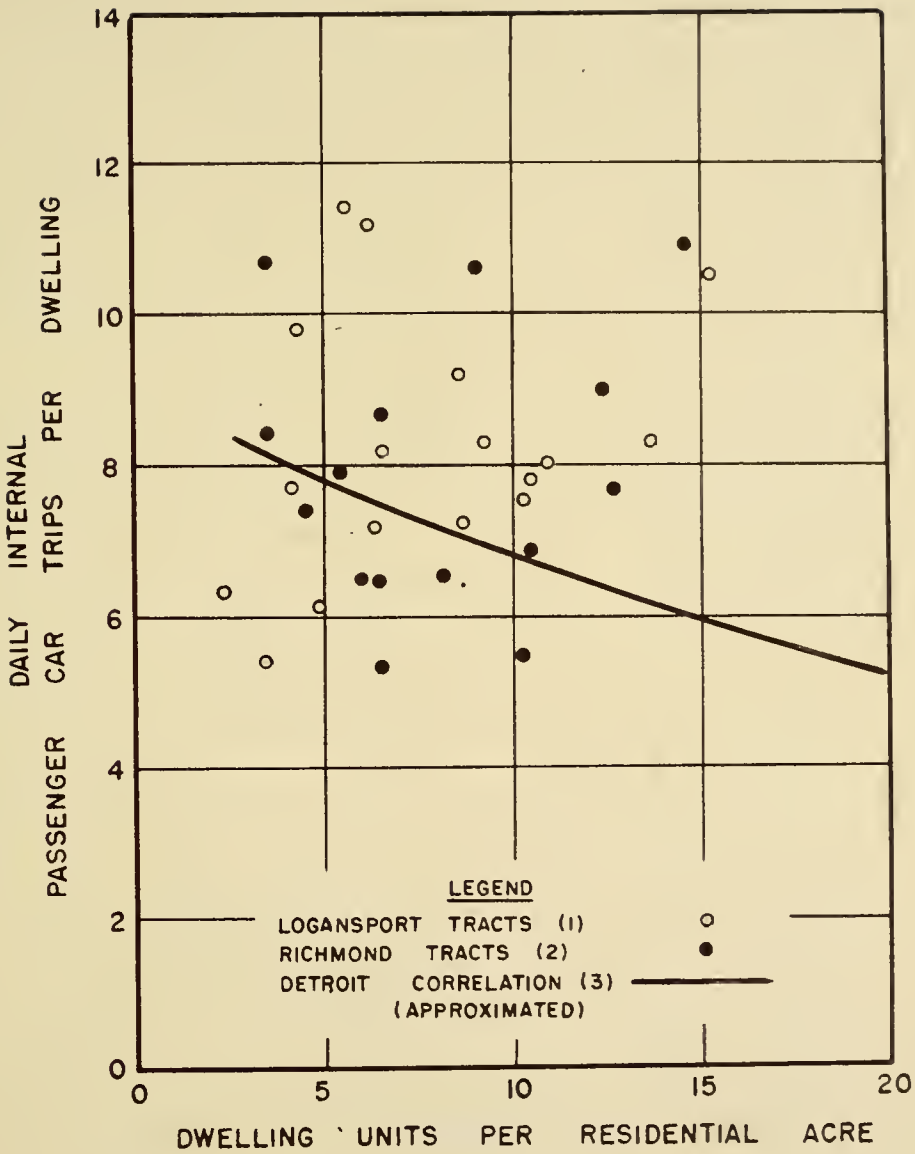
This would seem to indicate that in the survey tracts of Richmond and Logansport there is no evidence that the number of car trips made by the residents of an area has any relationship with the dwelling density of that area or with its proximity to the CBD. However, evidence that the distance from the CBD has some effect on residential trips is in the data shown in Table 5 and on Figure 10. Here it can be seen



NOTES :
(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY
(3) SOURCE : DETROIT METROPOLITAN AREA TRAFFIC SURVEY

CORRELATION OF TRIPS AND CARS PER DWELLING

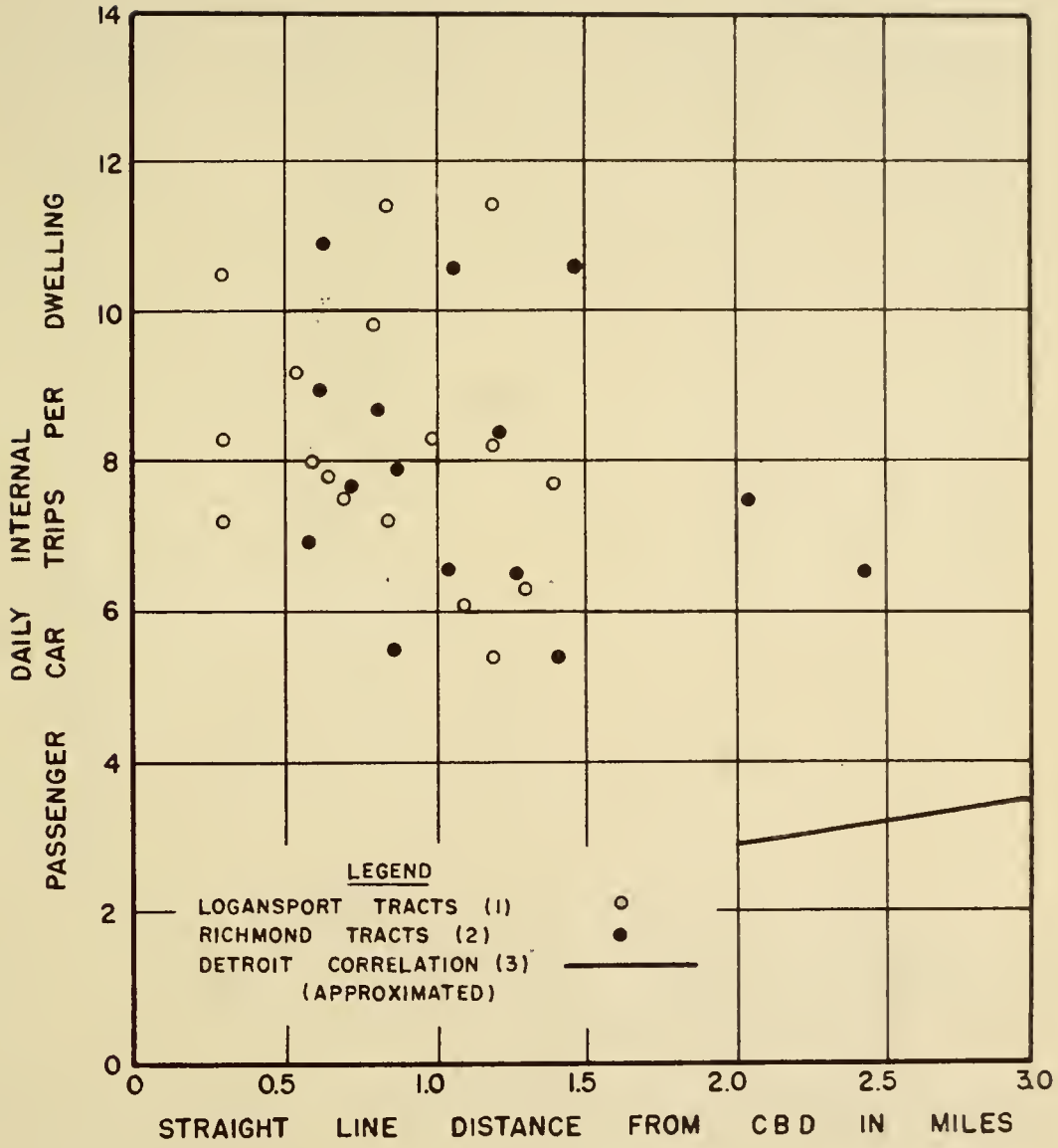
FIGURE 7



NOTES:
(1) SOURCE: LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE: RICHMOND, INDIANA TRAFFIC SURVEY
(3) SOURCE: DETROIT METROPOLITAN AREA TRAFFIC SURVEY

CORRELATION OF TRIPS AND RESIDENTIAL DENSITY

FIGURE 8



NOTES :
(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY
(3) SOURCE : DETROIT METROPOLITAN AREA TRAFFIC SURVEY

CORRELATION OF TRIPS PER DWELLING AND DISTANCE FROM CBD

FIGURE 9

Table 5

Internal Passenger Car Trips Per Residential Acre

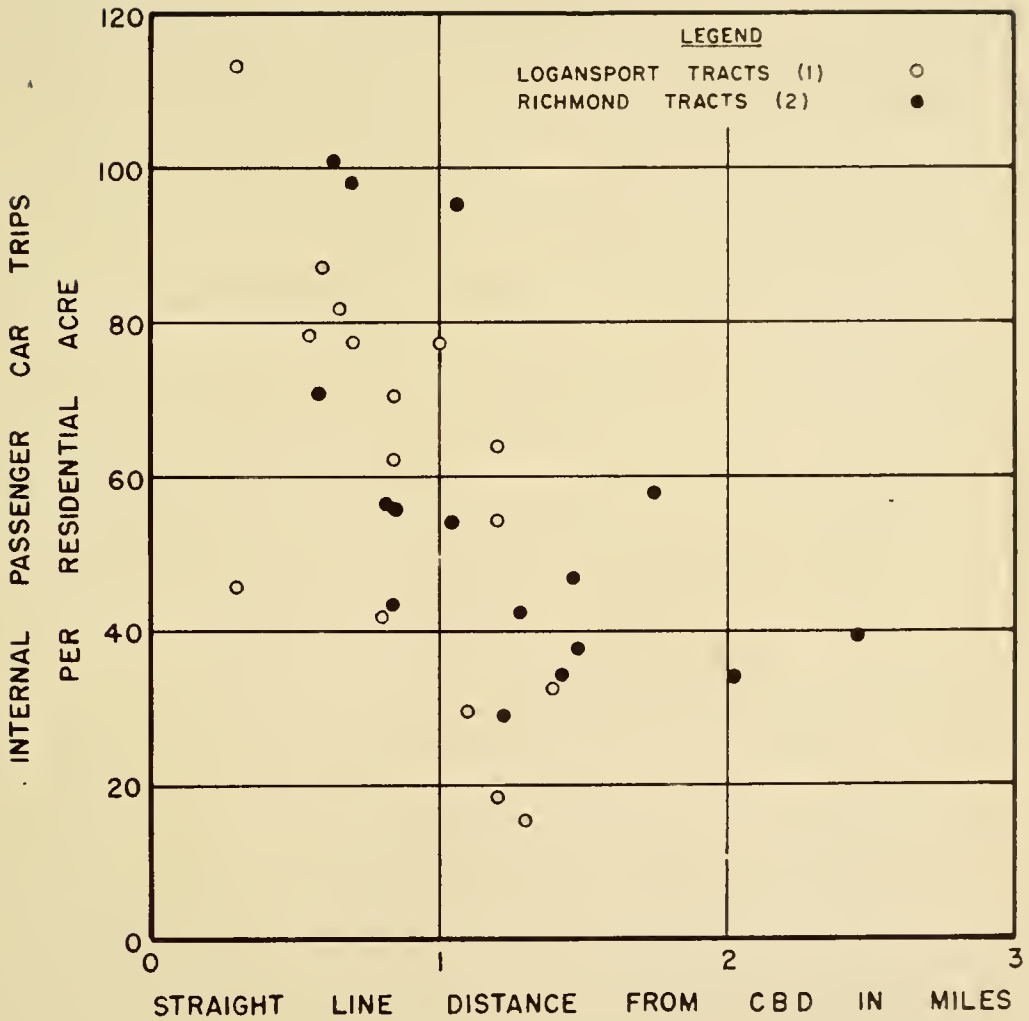
Logansport		Richmond	
Residential Tract Number[1]	Internal Car Trips Per Res. Acre[2][3]	Residential Tract Number[1]	Internal Car Trips Per Res. Acre[2][3]
3	42.0	2	39.0
8	82.0	6	54.0
10	62.6	10	95.4
11	19.0	11	111.2
12	29.8	12	57.0
13	70.1	23	56.1
14	15.5	24	34.0
15	78.6	26	37.6
16	45.8	27	57.7
17	160.6	28	33.9
19	113.6	30	42.1
20	215.7	32	29.6
23	77.5	33	159.3
25	87.5	34	71.6
26	77.6	35	43.1
27	64.0	36	97.9
28	54.2	37	47.3
29	32.4		

Notes:

1. Selected survey tracts of predominantly residential land use.

2. Car trip data from 1952 survey summary of average weekday internal passenger car trips: data expanded from post card sample to 100 per cent screenline check.

3. Residential acreage scaled from 1952 land use map.



NOTES :
(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY

CORRELATION OF TRIPS PER ACRE AND DISTANCE FROM CBD

FIGURE 10

that in the residential tracts of Logansport and Richmond at least, the number of car trips per residential acre drops sharply beyond a one mile radius of the CBD. Again, the variance from the apparent correlation discloses that distance is not the only factor affecting residential trips.

Additional data which were considered as having a possible connection with trip generation were collected for the selected residential tracts. The importance of economics has been indicated in a study of Washington, D.C., where a type of residence and economic class were seen to affect ownership and trips (23). The information presented in Table 6 suggests that in those Richmond and Logansport residential tracts where there are more cars per capita there are also more trips per dwelling. The same data, shown graphically on Figure 11, makes it apparent that ownership alone cannot be used to estimate trips, but that it must have some influence.

It would appear to follow that ownership might show even greater correlation with the number of car trips made per person residing in a residential tract. Figure 12 indicates that this correlation may very well exist, but that the frequent error of nearly one trip per capita from any regression line renders the correlation less precise than is necessary for use in making estimates. The ownership and population factors definitely carry some weight, which, when determined, might be used with other factors in developing an equation with which the number of trips generated in any tract could be estimated.

Table 6

Logansport and Richmond Ownership-Trip Data

Logansport				Richmond			
Res.[1] Tract No.	Est.[2] Tract Pop'n	Internal[3] Car Trips per Cap.	Cars[4] Per Cap.	Res.[1] Tract No.	Est.[2] Tract Pop'n	Internal[3] Car Trips Per Cap.	Cars[4] Per Cap.
3	955	3.13	.34	2	204	1.91	.17
8	2060	2.54	.31	6	3581	1.96	.25
10	1400	2.06	.27	10	2280	3.43	.33
11	267	1.63	.28	11	2219	2.86	.29
12	1018	1.78	.27	12	1816	2.76	.33
13	354	3.56	.34	23	2647	1.38	.19
14	249	1.55	.18	24	1014	1.34	.19
15	1452	2.92	.32	26	1057	3.55	.28
16	106	2.16	.32	27	228	5.31	.38
17	370	3.47	.27	28	622	2.18	.25
19	854	2.52	.27	30	1558	1.87	.26
20	487	7.08	.30	32	965	2.45	.26
23	1662	2.10	.22	33	1740	3.39	.29
25	955	2.57	.33	34	4315	2.26	.27
26	1372	2.66	.30	35	2170	2.78	.35
27	1389	3.46	.36	36	5001	2.45	.27
28	955	2.21	.28	37	751	6.29	.33
29	431	2.31	.28				

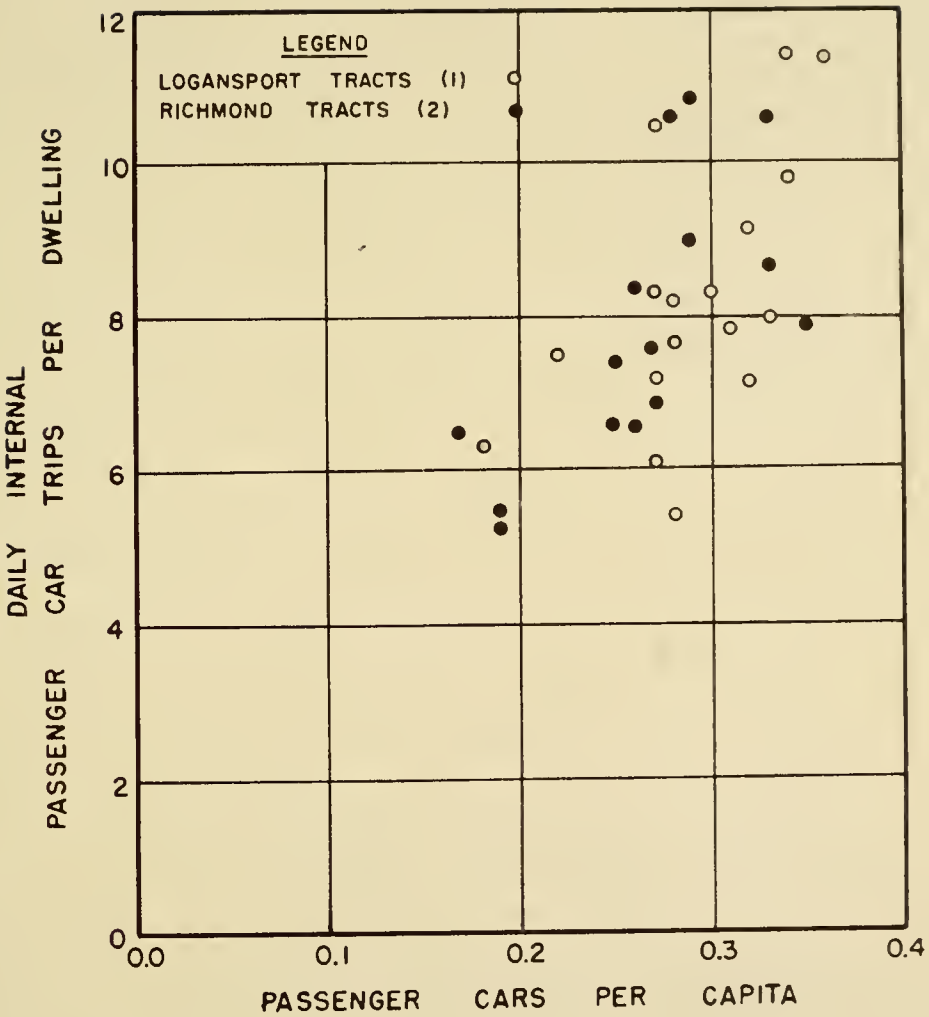
Notes:

1. Selected residential tracts.

2. Populations estimated from 1950 census and dwelling unit data.

3. Trip data from survey O-D charts.

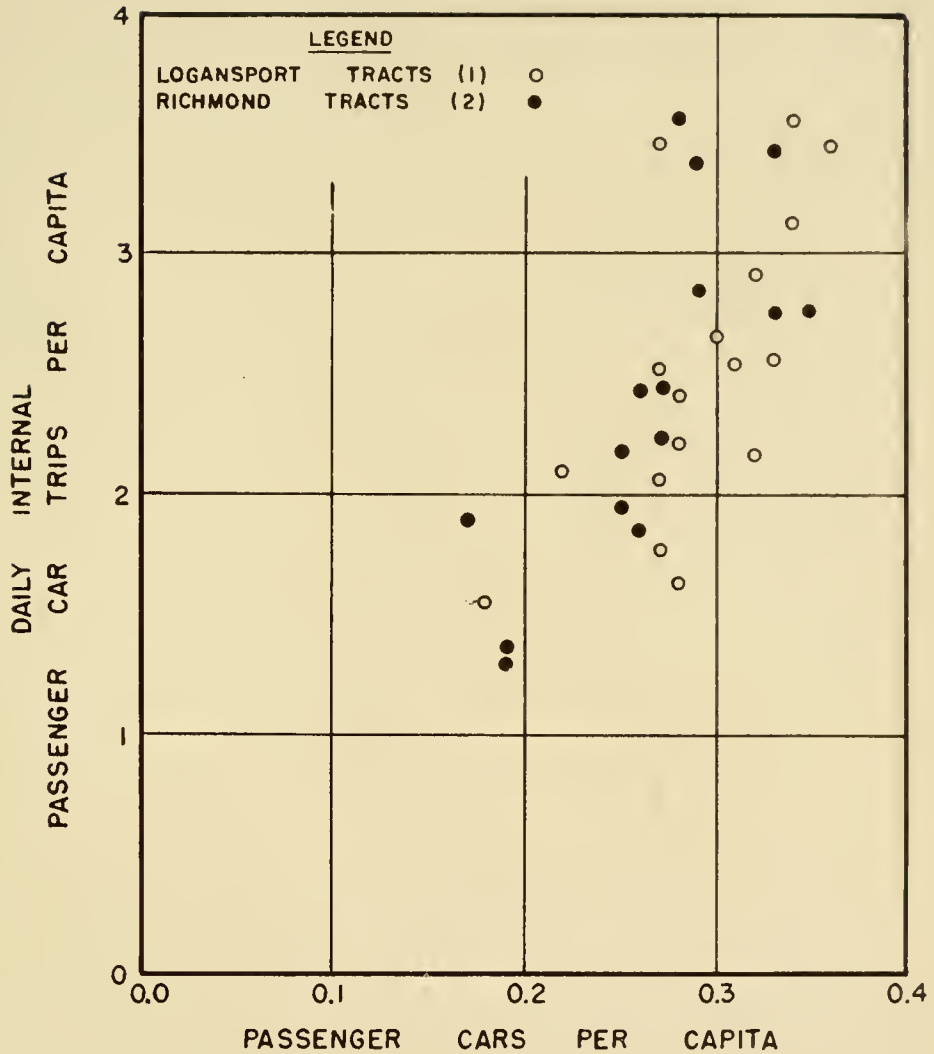
4. Source: Official registration lists as of date of survey.



NOTES :
(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY

CORRELATION OF TRIPS PER DWELLING AND CARS PER CAPITA

FIGURE 11



NOTES :
(1) SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY

CORRELATION OF TRIPS PER CAPITA AND CARS PER CAPITA

FIGURE 12

Trips Generated by All Tracts

Up to this point the investigations dealt with the trips generated by the CBD and by selected residential tracts. The next step was the examination of trip data for all survey tracts, in an attempt to discover correlations which might be used to make volume estimates for tracts having any land use mixture.

Since "pure" land use areas were isolated in the Detroit study (5), it was possible to obtain the number of internal trips per acre by land use and by "ring" of distance from the CBD. If these values were proved consistent for all cities or for particular classes of cities, then it would be feasible to use measured land use acreage and distances from the CBD to estimate the generated trips for any tract. It was decided that, although the Logansport and Richmond trip origins and destinations had not been classified as to land use, the trip-land use data should be examined, and, if possible, the trips-per-acre factors deduced.

Acreages of residential, commercial, industrial, and institutional land were measured on large land use maps prepared at the time of survey and based on field inventory. The measurements were recorded by portions of tracts lying within concentric rings, one-half mile in width, surrounding the CBD. These rings and the tracts lying in them are shown on Figures 1 and 2.

It was found that values of trips per land use acre arrived at through a trial-and-error procedure did not hold true for all acreage in a given ring and tract. These values, therefore, lack the reliability required for use in estimating trips generated by any tract having any

land use mixture.

During the investigation of the effects of land use acreage on trip generation, considerable doubt was aroused that the acre is a unit which properly measures an urban characteristic. The intensity of use varies greatly within the same land use category. A railroad yard located in Tract 22 of the Richmond area covers about 105 acres of land which must be classified as industrial and generates only about 540 daily trips to and from other tracts, while three industries located in Tract 4 cover about 130 acres and generate over 8000 trips. Both of these industrial zones are from one to two and one-half miles from the CBD as can be seen on Figure 2. Commercial acreage in a suburban shopping center would be expected to generate more trips than that of an airport. It is obvious that any trip estimates based on land use acreage must be adjusted in some way to reflect varying intensities of land use.

Since residential tract population appeared to have the strongest relationship with car trips for the Logansport and Richmond data (Figure 6), it was considered necessary to observe the effect of the population of any tract on its total trips. In so doing, it was realized that the effect could be very different for the various land use areas. For this reason the predominant land use or uses of each tract were noted as the data were compiled. These data are shown in Table 7.

Figure 13 shows the same information graphically and suggests that population may very well be a starting point in trip estimating. The points were originally plotted with a more complete land use

Table 7

Tract Population - Trip Data

Logansport				Richmond			
Tract No.	Land Use[1]	Est.[2] Tract Pop'n	Total[3] Internal Trips	Tract No.	Land Use[1]	Est.[4] Tract Pop'n	Total[5] Internal Trips
1	RU	342	420	1	RU	143	511
2	I-R	1434	6200	2	R-RU	204	477
3	R-RU	955	3314	3	I	31	1411
4	RU	32	33	4	I	53	8491
5	I	42	1824	5	I	0	705
6	I-R	495	1967	6	R	3581	8011
7	R-C	1108	3503	7	I-C	333	6560
8	R	2060	6013	8	R-RE	2107	9097
9	I-C	193	3080	9	IN	0	900
10	R	1400	3073	10	R	2280	9481
11	R-RU	267	444	11	R	2219	7770
12	R-RU	1018	1970	12	R	1816	5968
13	R-RU	354	1423	20	I	298	2474
14	R-RU	249	497	21	I	671	11190
15	R	1452	4658	22	I	3	548
16	R	106	254	23	R-RU	2647	4468
17	R	370	1436	24	R-RU	1014	1920
18	CBD	885	23103	25	RE	58	2245
19	R	854	2388	26	R-RU	1057	4536
20	R	487	3731	27	R-RU	228	1366
21	C	150	1403	28	R-RU	622	1512
22	I	0	1523	29	I-RU	47	505
23	R	1662	4184	30	R-RU	1558	3258
24	R-C	1243	5280	31	I	639	7294
25	R	955	2659	32	R-RU	965	2805
26	R	1372	4006	33	R	1740	7069
27	R	1389	5217	34	R	4315	11550
28	R	955	2425	35	R	2170	7147
29	R-RU	431	1158	36	R	5001	14016
30	RU	102	241	37	R-RU	751	5321
31	R-IN	983	4427	41	IN-R	946	3027
		23345	53597	42	R-C	1110	4354
				43	R-C	1112	6353
				44	R-C	1716	4284
				50	CBD	858	5569
				51	CBD	315	13714
				52	CBD	400	8959
						43008	194866

(continued)

Table 7 (continued)

Notes:

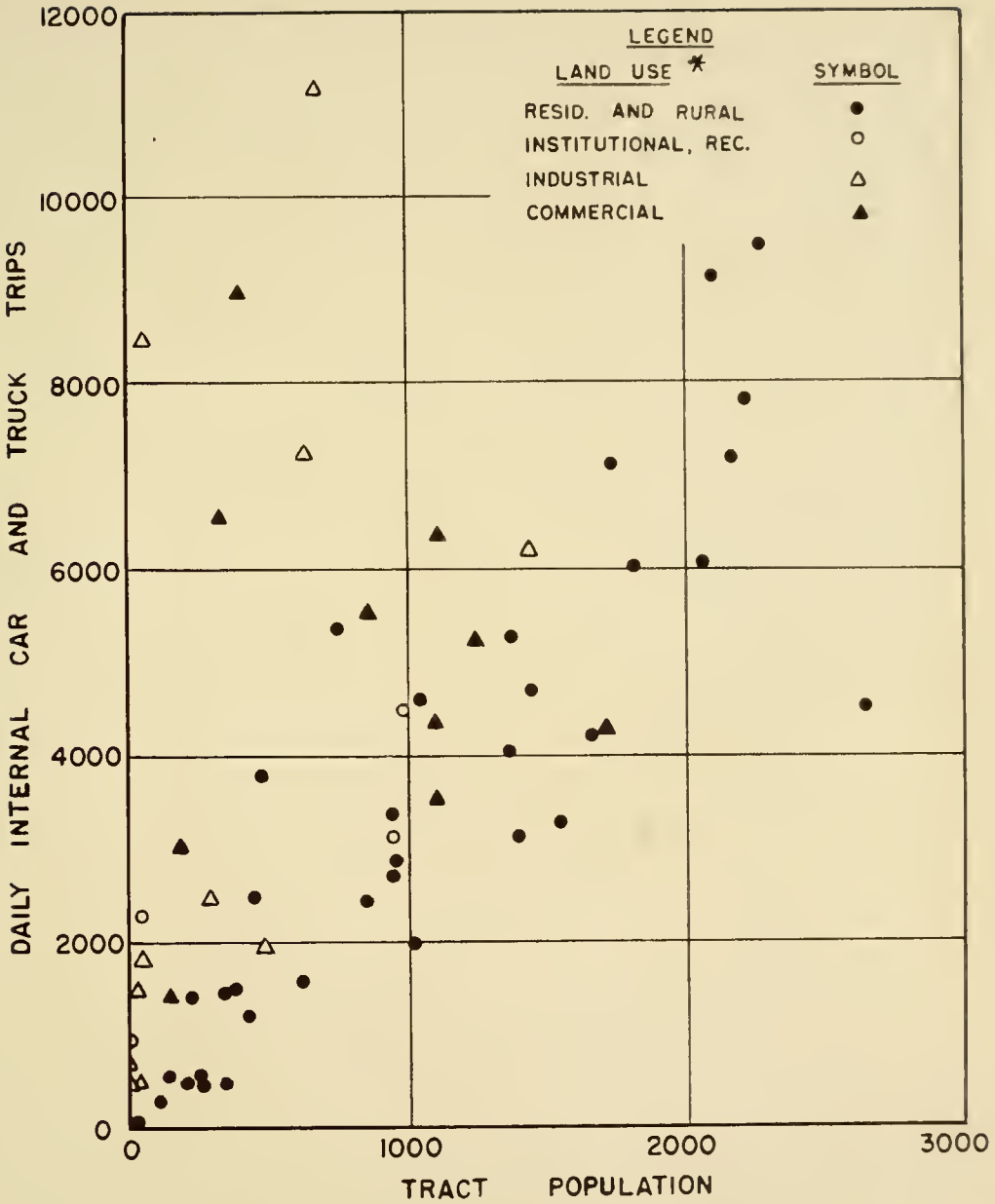
1. Predominant land use symbols
   - R Residential
   - RU Rural, Undeveloped
   - I Industrial
   - Re Recreational
   - In Institutional
   - CBD Central Business District

2. Source: home interview during survey

3. Source: Logansport, Indiana survey report

4. Source: Census count sheets, Sanborn maps, and survey land use checks.

5. Richmond, Indiana, survey report.



NOTES :
* PREDOMINATE LAND USE OF TRACTS
SOURCE : LOGANSPORT & RICHMOND, INDIANA TRAFFIC SURVEYS

CORRELATION OF INTERNAL TRIPS AND TRACT POPULATIONS

FIGURE 13

breakdown, but this was found to be unnecessary. As might be expected, trips generated by the rural (largely undeveloped) and residential tracts have a definite trend of increase with population increase. The industrial and commercial tracts, as well as some of the institutional and recreational tracts, obviously do not follow this pattern. The exceptions were found to be tracts having a less dominating single usage and a larger population.

It was considered possible that, starting with a minimum curve from which it would be possible to estimate trips generated by population alone in tracts of least ownership, the number of trips above that curve generated by all other tracts could be analyzed and perhaps estimated as a function of certain tract characteristics. On the basis of the observations made in previous paragraphs and careful consideration of the pertinence, availability, and accuracy of data collected from numerous sources, the following tract characteristics are recommended for such a procedure:

1. Passenger cars per capita,
2. Number of employees,
3. Number of retail sales.

These "properties" of a tract are believed to be usually convenient to measure, have been shown by other studies to affect trip generation, and have a rational connection with number of trips.

The source of vehicle registration information and the procedures for estimating population for Logansport and Richmond have been described.

The reported employment by quarter year of all business establishments subscribing to unemployment insurance or employing eight or

more persons for any twenty-week period were made available on a limited basis by the Indiana Employment Security Division. In addition to small concerns or self-employed individuals without unemployment insurance, the records kept by this division did not include employment data for government or other non-profit businesses, for railroad companies, or for agriculture. These data, which may be important in certain tracts, could ordinarily be found by consulting a city directory, which may show average employment, or by actually canvassing those businesses not reporting. In this particular study the city directories did not show employment, and canvassing was not practical since information as of the dates of survey rather than current data was required. The city and telephone directories dated nearest the date of survey, as well as survey location and address codes, were used to locate each business on which employment data were obtained, and to list known tract employment. This was later expanded on the basis of the number of additional stores and businesses found in the tract to obtain an employment estimate for each tract.

Additional information, which also might be best found by a canvass of small businesses and of all other retail establishments, is the average number of daily retail sales occurring in each tract. Canvassing was considered impractical for this study which was not of current conditions. The best alternative was expected to be past records of either amounts or volumes of sales. It appeared that these records do not exist in Indiana for all individual businesses, and this was verified by the Logansport Chamber of Commerce, a Richmond newspaper, and the Bureau of Business Research at Indiana University.

For these two cities, the best indication of the attraction in a tract at the time of survey due to retail sales was the number, and in some cases, the employment, of retail stores.

With the understanding that the measurements of tract employment and retail characteristics might be considerably less than desirable for some tracts, an attempt was made to explain generated trips for each Logansport tract. Basic estimates of those explained by ownership and population were made from minimum curves fitted by freehand to the data shown on Figures 6 and 13. Considerations of work trip characteristics, relative attractiveness of various types of retail stores, and the remaining trip volumes themselves suggested trial values of trips per employee, trips per retail store, and trips generated by other attractions such as terminal buildings, schools, and other public land. It was found that with these preliminary values trip estimates for 10 of the 31 tracts were within 5 per cent of the comparable values calculated from the post card O.D. survey. The largest discrepancies were in tracts having a large amount of undeveloped land, a number of industries, or a use mixture including dispersed commercial establishments.

Much of the error can be attributed to the inadequacy of employment and retail data. Probably the most significant observance made in the analysis was that there is a definite need for more knowledge of the trip generation characteristics of retail and working places and of schools, public, and office buildings, and other centers of activity. It is highly recommended that additional research be performed, directed specifically toward the determination of average

values of trip per employee, trip per retail sale, etc., which may be used to make reliable estimates, and the factors affecting these values.

Inter-Tract Trips

The end result of an origin-destination study is the production of a visual picture of the pattern of daily traffic desires, which can be used in planning improvements in the facilities which will best satisfy those desires. The object of this study, as stated previously, is to contribute to the development of an approach which can be used in approximating these desire line movements. It has been shown thus far, that the total internal trips generated by an urban area, or a tract within that area, cannot be reliably estimated on the basis of one or two measured characteristics of that area. However, it was believed that there existed the possibility that inter-tract trips or desire line volumes can be estimated without an accurate estimate of total tract trips. For this reason the Logansport and Richmond inter-tract data were compiled, certain characteristics of the connected tracts were measured or estimated, and correlations suggested by other investigators or by the data itself were investigated.

Inter-tract volumes by definition do not account for those trips having both origin and destination in the same tract, and, therefore, the sum of all trips into and out of an area would not be expected to always equal the total tract-generated trips. Intra-tract trips are usually of little significance to the planner and are not included on most desire line maps.

CBD-Tract Trips

One is immediately impressed with the spoke-like pattern into which the internal desire lines of a city arrange themselves. This is particularly true of cities under 50,000 population, where it has been observed that the CBD attracts a larger proportion of trips than it does in larger cities (11). It is clear that a knowledge of the trips between the CBD and other important tracts will provide an essential part of the entire internal O-D pattern.

As a result of the research at Yale a set of curves was developed by which several variables are translated into three factors forming an estimate of trips per registered car between any given tract and the CBD (1). The variables required to make these estimates are: metropolitan area population, over-the-road distances between the tract center and the CBD, persons per car in each tract, and the per cent of the metropolitan area population within the radius determined by the tract centroid. Using the three charts presented in Wynn's paper, three factors can be found which reflect the effects of city size, tract ownership, and city compactness. The required data for the Logansport and Richmond tracts are shown in Tables 8 and 9.

The compactness of the population of a city in relation to any tract is expressed as the per cent of the total area population which lies within a radius of CBD defined by the distance from the CBD to the tract center. In order to obtain this percentage for each Logansport and Richmond tract, the population of each half-mile "ring" was found. This was done by proportioning tract population

Table 8

Logansport CBD-Tract Trip Estimates

Tract No.	Str. Line[1] Radius From CBD	Street[1] Dist. From CBD	Reg.[2] Pass. Cars	Person[3] Per Car	Percentage[4] Population Within Radius
1	1.1	1.2	89	3.8	71.9
2	1.0	1.0	422	3.4	66.3
3	0.8	1.0	324	2.9	48.8
4	1.6	2.0	10	3.2	94.9
5	0.4	0.5	22	1.9	18.1
6	0.5	0.6	118	4.2	22.6
7	0.3	0.4	356	3.1	13.6
8	0.7	0.8	643	3.2	40.1
9	1.0	1.2	67	2.9	66.3
10	0.9	1.0	382	3.7	57.6
11	1.2	1.4	74	3.6	77.4
12	1.1	1.2	270	3.8	71.9
13	0.9	1.0	119	3.0	57.6
14	1.3	1.8	44	5.7	83.0
15	0.6	0.6	459	3.2	31.3
16	0.3	0.4	34	3.1	13.6
17	0.3	0.3	101	3.7	13.6
19	0.3	0.4	227	3.8	13.6
20	0.4	0.4	148	3.3	18.1
21	0.3	0.4	42	3.6	13.6
22	1.2	1.4	0	-	77.4
23	0.7	0.8	373	4.5	40.1
24	0.6	0.7	339	3.7	31.3
25	0.6	0.7	313	3.1	31.3
26	1.0	1.1	413	3.3	66.3
27	1.2	1.3	499	2.8	77.4
28	1.2	1.3	269	3.6	77.4
29	1.4	1.5	123	3.5	84.3
30	2.0	2.4	36	2.8	98.4
31	1.7	1.7	366	2.7	92.5

Notes:

1. Scaled straight line and over-the-road mileages between tract center and CBD.
2. Source: Survey report summary of registration lists.
3. Tract populations estimated from 1950 U.S. Census by district and dwelling distribution.
4. Interpolated from half-mile accumulative values (see text).

Table 9

Richmond-CBD-Tract Trip Estimates

Tract No.	Str. Line[1] Radius From CBD	Street[1] Dist. From CBD	Reg.[2] Pass. Cars	Person[3] Per Car	Percentage Population[4] Within Radius
1	2.14	3.12	30	4.8	98.8
2	2.44	2.50	36	5.7	99.6
3	1.95	2.40	79	0.4	97.4
4	1.97	2.37	19	2.8	97.8
5	2.33	2.86	1	0.0	99.3
6	1.04	1.33	910	3.9	69.1
7	1.06	1.43	286	1.2	69.9
8	1.74	1.98	682	3.1	93.3
9	1.22	1.39	46	0.0	76.7
10	1.07	1.09	746	3.1	70.4
11	0.63	0.73	654	3.4	33.4
12	0.81	1.04	591	3.1	49.9
20	0.40	0.39	46	6.5	17.1
21	0.56	0.75	258	2.6	26.9
22	1.33	1.48	0	-	81.3
23	0.85	1.11	508	5.2	53.6
24	1.41	1.75	193	5.3	84.7
25	1.79	2.08	23	2.5	94.2
26	1.48	1.84	298	3.5	87.6
27	1.74	2.53	86	2.7	93.3
28	2.02	2.46	153	4.1	98.5
29	2.03	2.13	9	5.2	98.5
30	1.28	1.45	404	3.9	79.2
31	1.13	1.43	225	2.8	72.9
32	1.22	1.62	253	3.8	76.7
33	0.62	0.62	512	3.4	32.4
34	0.59	0.91	1160	3.7	29.7
35	0.83	1.22	756	2.9	51.8
36	0.70	0.90	1366	3.7	39.8
37	1.47	1.53	245	3.1	87.2
41	0.36	0.48	242	3.9	15.4
42	0.25	0.34	301	3.7	10.7
43	0.30	0.40	3.28	3.4	12.8
44	0.19	0.30	353	4.9	8.1

(continued)

Table 9 (continued)

Notes:

1. Scaled straight line and over-the-road mileages between tract center and CBD.
2. Source: Survey report summary of registration lists.
3. Tract populations estimated from 1950 U.S. Census by district and dwelling distribution.
4. Interpolated from half-mile accumulative values (see text).

---

estimates by dwelling unit distribution. The ring populations are shown in Table 10 along with accumulative values and percentages. The graphic portrayals of the compactness or population distribution of the two cities are shown on Figure 14. From the accumulative percentage values calculated for each half-mile circle, the value for the distance to any tract center can be interpolated. This procedure for arriving at these values appears to be the most practical.

Probably because most of the data upon which the Yale charts are based was from more populated areas, extrapolation was necessary to obtain the factors for the Logansport-Richmond data. CBD-tract trips estimated from these factors were found to differ considerably from the survey values. This was understandable, since the extrapolations were in a practically unexplored area.

In making the estimates the effects which the tract and trip characteristics had upon volumes of exchange were very noticeable, if difficult to measure. Because of this, and also since the CBD-tract trips were considered an essential part of internal movement, an attempt was made to determine the net effect of the variable.

Table 10

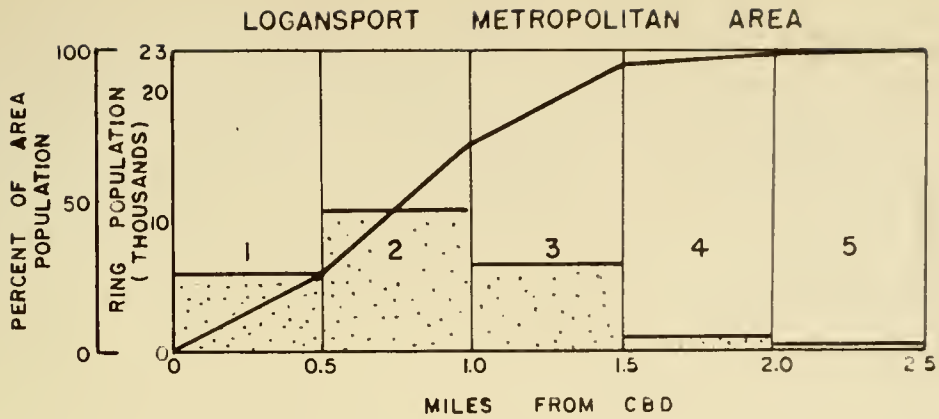
Population by Half-Mile Rings

Ring No.[1]	Radii[1] (Miles)	Est.[2] Ring Pop'n	Accum. Pop'n.	Percentage of Total	Accum. Percentage of Total
		Logansport			
1	0.0 - 0.5	5269	5269	22.6	22.6
2	0.5 - 1.0	10211	15480	43.7	66.3
3	1.0 - 1.5	6497	21977	27.8	94.1
4	1.5 - 2.0	939	22916	4.1	98.2
5	2.0 - 2.5	429	23345	1.8	100.0
		Richmond			
1	0.0 - 0.5	9214	9214	21.4	21.4
2	0.5 - 1.0	19760	28974	46.0	67.4
3	1.0 - 1.5	9072	38046	21.1	88.5
4	1.5 - 2.0	4268	42314	9.9	98.4
5	2.0 - 2.5	627	42941	1.4	99.8
6	2.5 - 3.0	67	43008	0.2	100.0

Notes:

1. Rings are those portions of the survey areas lying between concentric circles whose radii are distances from the CBD and differ by one-half mile.

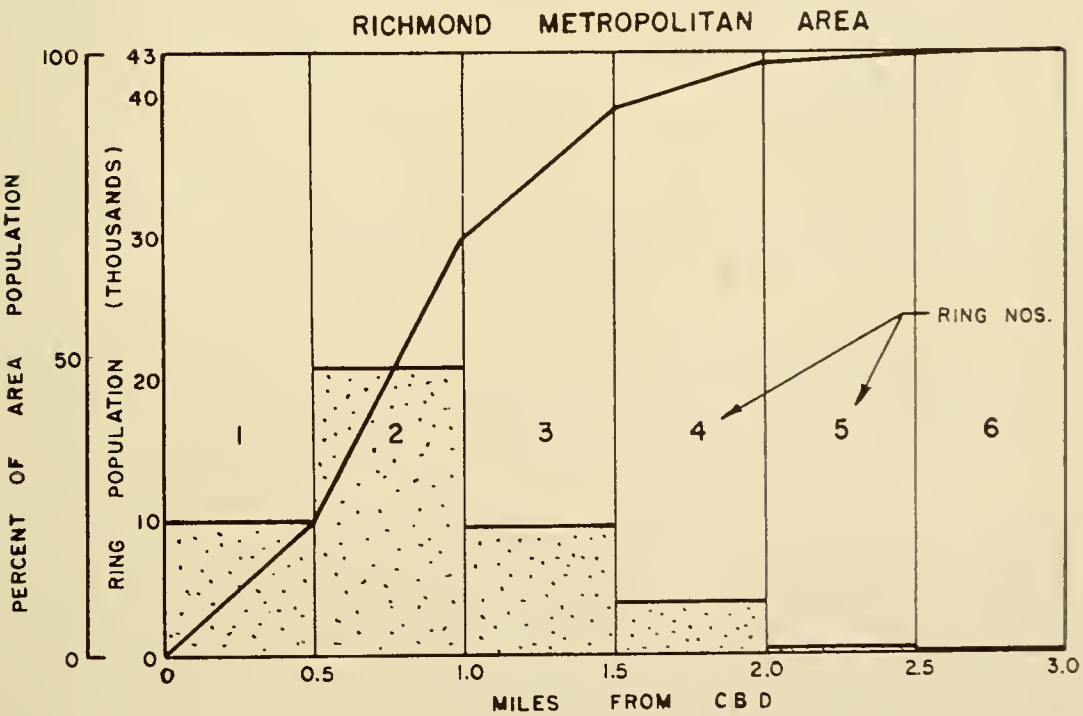
2. Source: Estimated tract populations distributed to rings according to dwelling unit distribution.



LEGEND

ESTIMATED POPULATION OF HALF-MILE RINGS

PERCENT OF TOTAL POPULATION WITHIN RADIUS



SOURCE : CENSUS DATA AND FIELD INVENTORIES AT DATES OF SURVEYS

LOGANSPORT AND RICHMOND POPULATION COMPACTNESS

FIGURE 14

A graphical method for obtaining net linear regression equations was employed. It was felt that a more precise method was not warranted because of the estimated quantities involved. This approach, described by Ezekiel (24) and used in the development of the charts in Wynn's paper (1), involves successive approximations and accounts for the combined effects of independent variables on the dependent variable. The regression lines are approached more rapidly when the intercorrelation of independent variables is not strong.

Daily trips per car between a tract and the CBD was used as the dependent variable, X_1. The independent variables were defined as follows:

X_2 .... Metropolitan area population in thousands

X_3 .... Persons per registered car in the tract

X_4 .... Percent of the area population within the radius defined as the straight line distance from the CBD to the tract center.

Regression equations were developed for Logansport and Richmond CBD-tract combinations grouped according to one-half mile increments of average length of trip.

The amount of intercorrelation of the independent variables was checked before the approximations by plotting each pair of variables against each other. Very little correlation was indicated. This suggests that the variables are well-chosen, in that their effects upon each other are small, making easier the combining of their effects upon the dependent variable.

The date required to perform the approximations are in Tables 8 and

9. Following the Ezekiel graphical method, lines were obtained for each half-mile length of trip which showed the approximate weight or coefficient of each variable for the equation:

$$X_1 = a + bX_2 + cX_3 + dX_4$$

The slope of the developed line in each case represented the value of the coefficient for the dependent variable. The "a" values were found by substituting mean figures for X_1, X_2, X_3, and X_4. The resulting estimation equations for average trip lengths are as follows:

0.5 miles: $x_1 = 2.28 - 0.0503\, x_2 + 0.56\, x_3 + 0.023\, x_4$

1.0 miles: $x_1 = 5.02 - 0.0250\, x_2 - 0.99\, x_3 + 0.038\, x_4$

1.5 miles: $x_1 = 0.73 - 0.0075\, x_2 - 0.90\, x_3 + 0.060\, x_4$

2.0 miles: $x_1 = 34.78 - 0.0225\, x_2 - 1.58\, x_3 - 0.283\, x_4$

2.5 miles: $x_1 = -45.29 + 0.6750\, x_2 - 0.25\, x_3 + 0.470\, x_4$

The x variables in these equations are defined:

x_1 = estimated trips per registered car between a tract and the CBD.

x_2 = metropolitan area population in thousands.

x_3 = persons per registered car in the tract.

x_4 = per cent of area population within the same radius of the CBD as is the tract center.

Because of the number of estimated values incorporated in both dependent and independent variables, no effort was made to actually calculate a correlation coefficient or otherwise indicate the amount of variability in CBD-tract trips which is explained by the other

three variables. However, in checking the work, estimates for each CBD-tract trip in Logansport and Richmond were made. It was observed that, although some large discrepancies occurred, numerous values agreed closely with survey values.

From results obtained in a recent study of trip attraction by land use in Washington, D.C., Mr. Wynn has further observed that the rate of trips generated by the CBD is higher and declines less rapidly with trip length than the rate of generation of other land uses. In this relationship the rate at which the CBD attracts trips was expressed in units of daily trips per 1,000 population (tract) between the tract and the CBD.

These rates, as well as trip lengths for all Logansport and Richmond CBD-tract combinations are shown in Table 11. Trip lengths were measured in terms of over-the-road or street mileage between the tract center and the CBD, and were scaled from large city maps. These values were used to observe any change in CBD attraction with length of trip.

The data, plotted on Figure 15, appear to show no such correlation for the CBD-tract trips in either city. Although person-trips are not strictly comparable with car and truck trips, the effect of trip length on CBD attraction in Washington is obviously not the same in either Logansport or Richmond. Since all such trips are relatively short in those cities, however, there is no indication as to whether or not distance may have greater effect beyond three miles. Inasmuch as this study concerned itself chiefly with trip patterns in cities where internal trips are short, CBD trip length was considered of

Table 11

CBD-Tract Trip Lengths and Rates of Generation

Logansport			Richmond		
Tract No.	Street[1] Dist. From CBD	CBD[2] Trips per 1000 Pop'n	Tract No.	Street[1] Dist. From CBD	CBD[2] Trips per 1000 Pop'n
1	1.2	412	1	3.12	510
2	1.0	998	2	2.50	475
3	1.0	1088	3	2.40	5290
4	2.0	0	4	2.37	12000
5	0.5	8000	5	2.86	*
6	0.6	879	6	1.33	282
7	0.4	937	7	1.43	2562
8	0.8	830	8	1.98	571
9	1.2	3207	9	1.39	*
10	1.0	547	10	1.09	671
11	1.4	622	11	0.73	508
12	1.2	445	12	1.04	510
13	1.0	1034	20	0.39	1134
14	1.8	683	21	0.75	2195
15	0.6	1037	22	1.48	17607
16	0.4	660	23	1.11	256
17	0.3	816	24	1.75	221
19	0.4	830	25	2.08	5534
20	0.4	1645	26	1.84	798
21	0.4	2273	27	2.53	1101
22	1.4	*	28	2.46	312
23	0.8	700	29	2.13	2106
24	0.7	1031	30	1.45	322
25	0.7	842	31	1.43	1307
26	1.1	779	32	1.62	432
27	1.3	1042	33	0.62	699
28	1.3	667	34	0.91	457
29	1.5	661	35	1.22	707
30	2.4	784	36	0.90	471
31	1.7	1399	37	1.53	1104
			41	0.48	486
			42	0.34	714
			43	0.40	934
			44	0.30	371

(continued).

Table 11 (continued)

Notes:

1. Scaled mileage from large street and tract map.
2. Computed from survey trip data and population estimates based on U.S. Census counts and on dwelling distribution.

* Infinite; tract has no population.

---

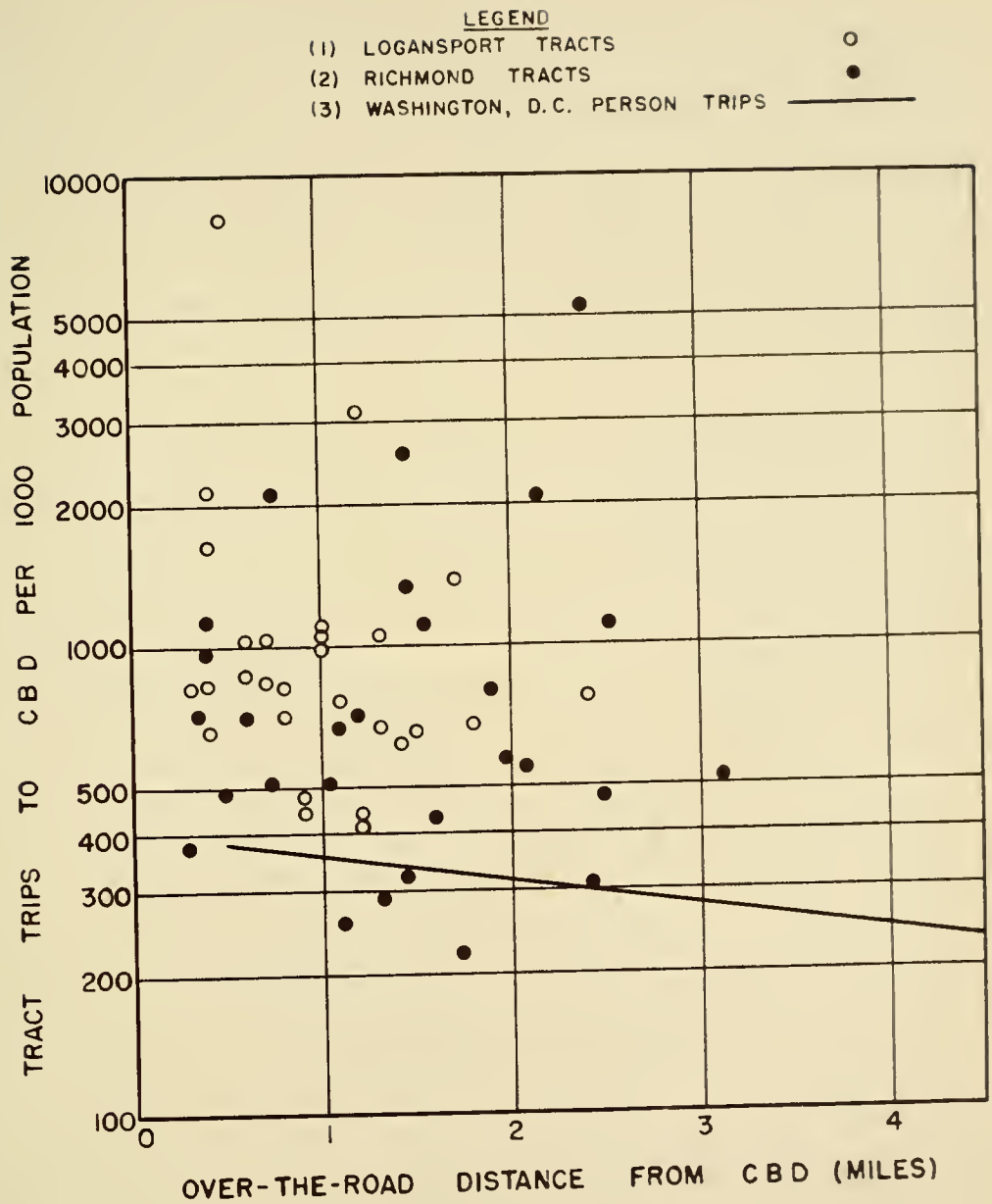
little value without modification by other factors.

Residential-Residential Tract Trips

It has been pointed out that trip volumes between two residential tracts contribute less to the complete O-D picture than do the CBD-generated trip. However, the possibility of several important inter-residential movements, and the fact that an accumulation of small movements can affect the major desire appearance, suggest that some attention be given to residential-residential tract trips.

It has been suggested that the rate at which trips are exchanged by residential tracts is affected not only by the length of trip, but also by the size of the metropolitan area and the ownership characteristics of the tracts involved. Wynn's paper indicates that these trips are generated at higher rates in smaller cities and between tracts of high vehicle ownership (1).

Because of the prohibitive amount of work involved in investigating all possible pairs of residential tracts, 15 pairs were selected for each of the two cities. These involved all combinations of the six most populated tracts in each city. It was found that this method of selection resulted in the investigation of nearly all important inter-residential movements. The tract pairs and the corresponding charac-



NOTES :

(1) SOURCE : LOGANSPORT TRAFFIC SURVEY

(2) SOURCE : RICHMOND TRAFFIC SURVEY

(3) SOURCE : F. H. WYNN, "INTRA-CITY TRAFFIC MOVEMENTS"

CORRELATION OF C B D - TRACT TRIP GENERATION AND TRIP LENGTH

FIGURE 15

teristics likely to affect rate of trip exchange are in Table 12.

The rate is expressed in terms of daily car and truck trips exchanged by the pair, tract "a" and tract "b", per 1,000 population of "a" per 1,000 population of "b". Trip lengths are scaled mileages between the apparent centers of land use of each pair along the most convenient existing streets. To observe what effect, if any, trip length had upon the rate of trip exchange, the chart on Figure 16 was drawn.

Although there is little correlation, it would appear that the rate of exchange between residential tracts in Logansport and Richmond declines somewhat more rapidly with trip length than it does in larger cities. The average rate is a little higher for Logansport than for Richmond and both rates are higher than those of the larger cities. This falls in line with the observation that the larger the city, the lower the rate. Although the rate is generally lower for trips between tracts of low ownership, the fact that ownership is more constant throughout Logansport and Richmond may account for the less striking difference as compared with the difference between the Washington, D.C. average (solid line) and low ownership (dotted line) rates.

It may be concluded that the actual volume of trips which are exchanged between any two residential tracts cannot be reliably estimated using these characteristics in the relationship shown on Figure 16. Indications are that one or more additional characteristics must be considered. The approach which has been used here, however, seems to suggest in a general way the effects of the basic characteristics which influence inter-residential trip generation.

Table 12

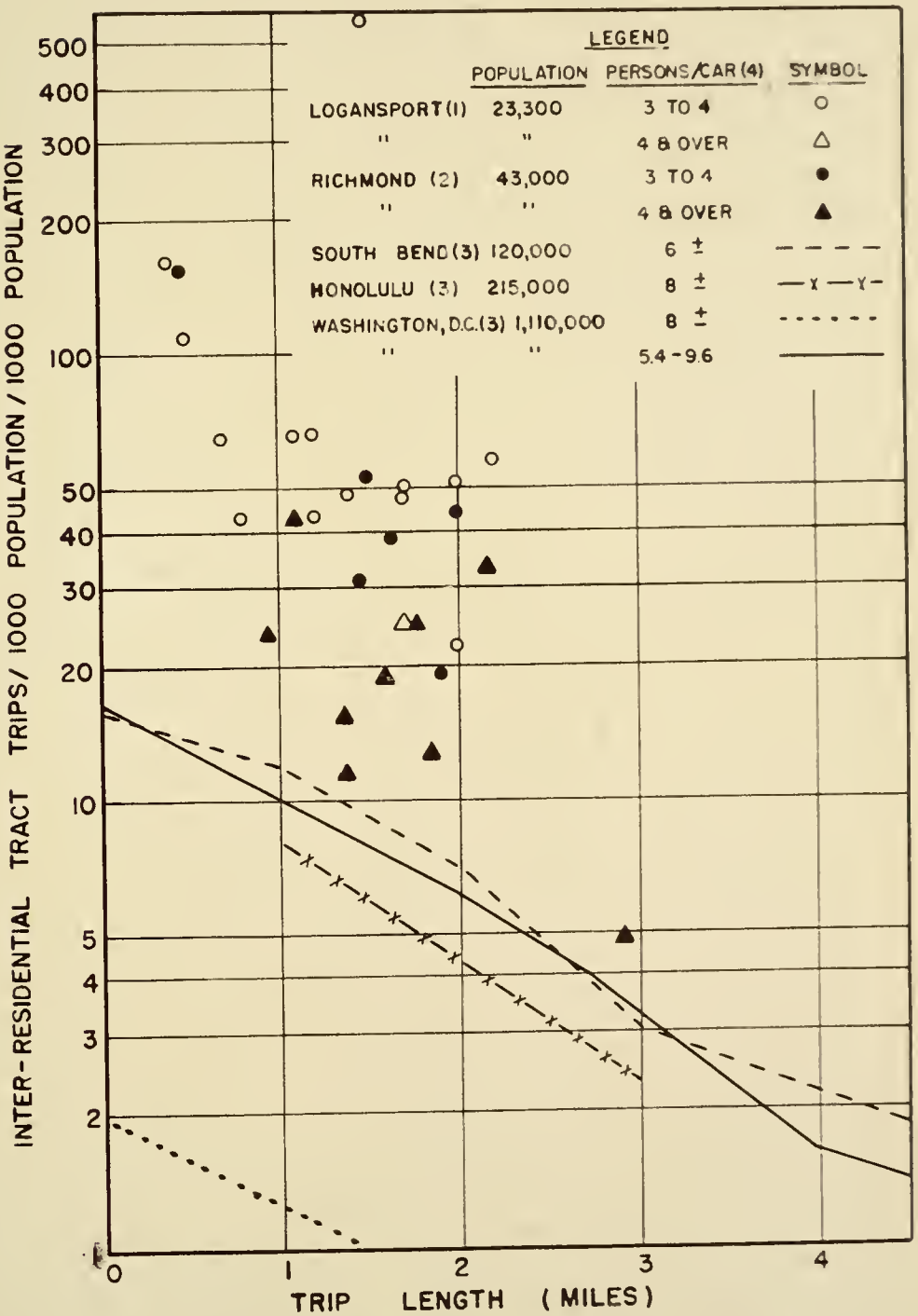
Inter-Residential Trip Data

Res. Tract[1] Pair a	b	Est. Pop'n[2] a	b	Trips[3] between a and b	Trips per 1000 pop'n	Trip Length[4] (mi.)	Persons per Car[5] a	b
				Logansport				
8	10	2060	1400	311	107.83	0.5	3.2	3.7
8	15	2060	1452	194	64.86	1.1	3.2	3.2
8	23	2060	1662	191	557.82	1.5	3.2	4.5
8	26	2060	1372	135	47.77	1.4	3.2	3.3
8	27	2060	1389	145	50.68	2.0	3.2	2.8
10	15	1400	1452	133	65.42	1.2	3.7	3.2
10	23	1400	1662	61	26.21	1.7	3.7	4.5
10	26	1400	1372	43	22.38	2.0	3.7	3.3
10	27	1400	1389	112	57.58	2.2	3.7	2.8
15	23	1452	1662	104	43.10	1.2	3.2	4.5
15	26	1452	1372	95	47.69	1.7	3.2	3.3
15	27	1452	1389	100	49.58	1.7	3.2	2.8
23	26	1662	1372	98	42.98	0.8	4.5	3.3
23	27	1662	1389	144	62.36	0.7	4.5	2.8
26	27	1372	1389	302	158.45	0.4	3.3	2.8
				Richmond				
6	10	3581	2280	254	31.11	1.46	3.9	3.1
6	11	3581	2219	421	52.98	1.50	3.9	3.4
6	23	3581	2647	176	18.57	1.58	3.9	5.2
6	34	3581	4315	75	4.85	2.90	3.9	5.3
6	36	3581	5001	335	18.71	1.91	3.9	3.7
10	11	2280	2219	766	151.41	0.48	3.1	3.4
10	23	2280	2647	76	12.59	1.84	3.1	5.2
10	34	2280	4315	328	33.34	2.16	3.1	5.3
10	36	2280	5001	501	43.94	1.99	3.1	3.7
11	23	2219	2647	90	15.32	1.35	3.4	5.2
11	34	2219	4315	247	25.80	1.77	3.4	5.3
11	36	2219	5001	426	38.39	1.63	3.4	3.7
23	34	2647	4315	129	11.29	1.36	5.2	5.3
23	36	2647	5001	305	23.04	0.95	5.2	3.7
34	36	4315	5001	917	42.50	1.10	5.3	3.7

Notes:

1. All pairs of residential tracts involving xis highest populated tracts.
2. Estimates based on 1950 U.S. Census by district and expanded by dwelling distribution.
3. Source: Richmond or Logansport Survey Reports
4. Scaled over-the-road mileage between tract centers
5. Registration data from survey summaries.

NOTES: (1) SOURCE: LOGANSPORT, INDIANA TRAFFIC SURVEY
(2) SOURCE: RICHMOND, INDIANA TRAFFIC SURVEY
(3) SOURCE: F. H. WYNN, "INTRA-CITY TRAFFIC MOVEMENTS"
(4) AVERAGES FOR REGISTERED CARS IN PAIRS OF TRACTS



INTER-RESIDENTIAL TRACT TRIPS
BY CITY, OWNERSHIP, AND TRIP LENGTH

FIGURE 16

Residential-Industrial Tract Trips

A section of a city in which is located several manufacturing plants or one large industry may very well generate more daily trips than any other section except the CBD. For this reason the industrial tract cannot be overlooked in any analysis of trip patterns. A number of studies and previous investigations have indicated that trips between industrial and commercial tracts are generally unimportant. One has only to consider experience to rationalize the fact that most trips to and from an industrial tract are for the purpose of going to work or returning home. An examination of trip movements between industrial and residential tracts, then, should provide the key to the analysis of industry-generated trips.

When considering inter-residential trips the rate at which the exchanges occur was a function of the population of each tract in a pair. The characteristic of an industrial tract which best indicates its size or attraction is probably the number of persons employed there. The labor force or number of employed persons living in residential tracts is likely to be the statistic most akin to trip volumes to industrial tracts. While census figures indicate that the Logansport and Richmond labor forces are equal to about 39 per cent and 43 per cent of their respective populations, the values for individual tracts are not readily determined. It can reasonably be assumed, however, that the labor force is generally distributed as is the population. This assumption, although conceivably untrue for certain work-live area relationships, allows the use of a residential tract's population, rather than its labor force, as the characteristic associated with

trips to work areas. The procedure used in estimating tract employees and population has been previously described.

Because of the large number of residential tracts in Logansport and Richmond, a great many industrial-residential pairs existed. For the purpose of observing characteristics of the exchange between such pairs, tracts were selected on the basis of ranking in population and number of employees. It was observed that a few pairs having a large exchange were not included. A study of all such tracts in Logansport and Richmond disclosed that neither size of population and employment nor length of trip can be used as criteria in selecting pairs having greatest interchange. In a complete analysis of the traffic pattern within a city it will probably be necessary to examine all possible pairs of residential-industrial tracts.

The tract pairs chosen arbitrarily to show the effect of trip length on rate of interchange were the six highest populated tracts in each city and all tracts having a predominantly industrial land use. The data for each tract pair are shown in Tables 13 and 14. The rate at which trip exchange occurs between any pair is expressed in terms of trips per 1,000 employees (of the industrial tract) per 1000 residents (of the residential tract). Trip length represents over-the-street mileage scaled from large tract and street maps.

Although the plotted data, shown in Figure 17, suggests large deviations from any line of regression, there is a clear indication that as trip mileage increases the rate of residential-industrial interchange decreases.

The difference between the two cities in rate of interchange

Table 13

Logansport Residential-Industrial Trip Data

Tract Ind.	Pair[1] Res.	Est.No.[2] Employed in Ind. Tract	Pop'n[3] Res. Tract	Trips[4] Between Tracts	Trips per 1000 Emp. per 1000 Pop'n	Trip[5] Length (mi.)
2	8	1194	2060	403	163.8	1.3
2	10	1194	1400	279	166.9	1.7
2	15	1194	1452	185	106.7	1.4
2	23	1194	1662	244	123.0	1.8
2	26	1194	1372	292	179.3	1.9
2	27	1194	1389	235	141.7	2.2
5	8	534	2060	100	90.9	0.9
5	10	534	1400	92	123.0	1.4
5	15	534	1452	90	116.1	1.2
5	23	534	1662	117	131.8	1.2
5	26	534	1372	102	139.2	1.2
5	27	534	1389	153	206.2	1.6
6	8	405	2060	166	199.0	0.5
6	10	405	1400	71	125.2	1.0
6	15	405	1452	45	76.5	1.1
6	23	405	1662	12	17.8	1.5
6	26	405	1372	47	84.5	1.6
6	27	405	1389	63	111.9	2.1
9	8	861	2060	271	152.8	0.5
9	10	861	1400	215	178.4	0.7
9	15	861	1452	202	161.6	1.6
9	23	861	1662	49	34.2	1.9
9	26	861	1372	121	102.5	2.1
9	27	861	1389	116	97.0	2.5

Notes:

1. Selected tracts of predominantly industrial or residential land use.

2. Estimates based on Employment Security Division records.

3. Estimates based on census and dwelling data.

4. Source: Logansport, Indiana Traffic Survey Report, 1952.

5. Over-the-street mileages scaled from large street and tract maps.

Table 14

Richmond Residential-Industrial Trip Data

Tract Ind.	Pair[1] Res.	Est. No.[2] Employed in Ind. Tract.	Pop'n[3] Res. Tract	Trips[4] Between Tracts	Trips per 1000 Emp. per 1000 Pop'n.	Trip[5] Length (mi.)
4	6	2323	3581	647	77.8	1.04
4	10	2323	2280	777	146.7	1.57
4	11	2323	2219	515	99.9	1.61
4	23	2323	2647	226	36.8	1.88
4	34	2323	4315	534	53.3	3.33
4	36	2323	5001	609	52.4	2.91
5	6	1806	3581	94	14.5	1.56
5	10	1806	2280	33	8.0	2.08
5	11	1806	2219	34	8.5	2.11
5	23	1806	2647	55	11.5	2.39
5	34	1806	4315	45	5.8	3.85
5	36	1806	5001	71	7.9	3.45
21	6	3658	3581	591	45.1	1.63
21	10	3658	2280	442	53.0	1.57
21	11	3658	2219	517	63.7	1.06
21	23	3658	2647	701	72.4	0.32
21	34	3658	4315	737	46.7	0.97
21	36	3658	5001	1015	55.5	0.58
31	6	1601	3581	306	53.4	2.91
31	10	1601	2280	247	67.7	2.22
31	11	1601	2219	170	47.8	1.81
31	23	1601	2647	165	38.9	2.60
31	34	1601	4315	610	88.3	1.03
31	36	1601	5001	483	60.3	2.05

Notes:

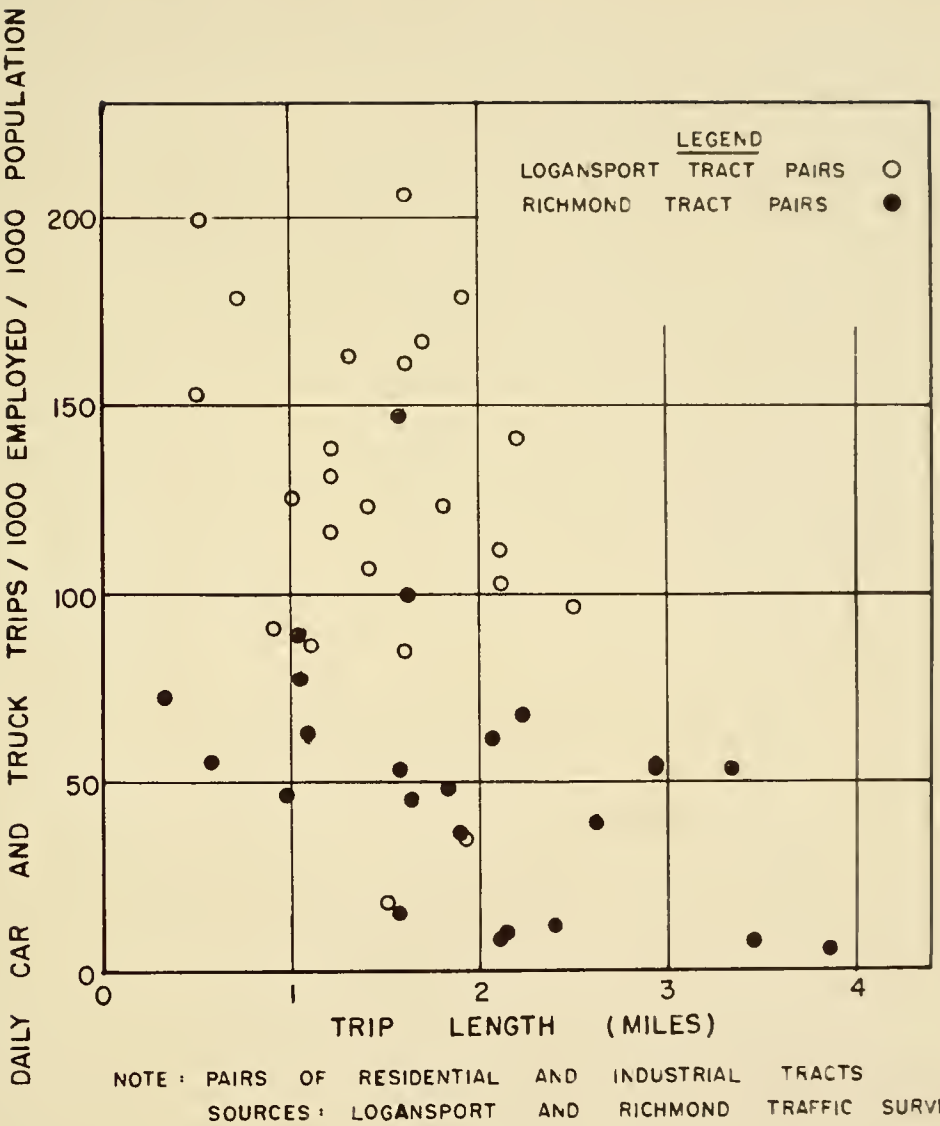
1. Selected tracts of predominantly industrial or residential land use.

2. Estimates based on Employment Security Division records.

3. Estimates based on census and dwelling data.

4. Source: Richmond, Indiana, Traffic Survey Report, 1952.

5. Over-the-street mileages scaled from large street and tract maps.



RESIDENTIAL – INDUSTRIAL TRACT TRIPS AND TRIP LENGTH

FIGURE 17

is also noteworthy. The shorter trips occurring in Logansport are understandable because of the smaller area and possibly greater proximity of residential and industrial tracts. The higher average rate, however, remains unexplained. It is possible that the difference may be accounted for by inaccuracies of trip or other estimates, the observed difference in ownership characteristics (see Figure 16), or differing passenger-per-car values.

Since a great deal of knowledge must yet be gained before estimates of residential-industrial interchange become reliable, special studies of important industrial tracts or plants may be necessary long after the analytic O-D survey procedure is otherwise satisfactorily developed. These studies in themselves could be expected to shed light on such trips.

One such study was performed during the Richmond, Indiana, survey (20). One tract was delineated so that it enclosed completely the grounds of a manufacturing plant. During the actual collection of O-D data the plant was operating at 28 per cent of its normal working force, and the trips were correspondingly multiplied by 3.6 to obtain average weekday values. At the same period a parking lot check showed that 2.82 trips per parked car were made to and from that tract. This factor, the average figure of 1.59 passengers per car for work, and the knowledge of the usual employment gave a separate estimate of average daily trips. The two estimates were found to differ by only one per cent, the small difference indicating a direct relationship of employees, vehicles, and trips.

A large number of similar studies, perhaps featuring O-D interviews or plant-distributed questionnaires, would very likely provide information useful in analyzing not only the generation characteristics of industrial zones, but also the distribution of trips to other zones.

Trip Distribution

After further refinement and development the procedure for estimating trip volumes between pairs of tracts can be expected to obtain directly many of the travel desires in a city. In order to supplement this procedure or to check and adjust the values obtained, it may be desirous to obtain estimates of the total trips generated by a certain land use zone. This may be done either by using the approaches described previously in this study or by running a special field count of trips into and out of a tract. The values obtained in this way show only tract generation, however, and not the exchange or desire lines between tracts. Knowing the total trips generated in a group of important tracts interconnected by a system of lines of potential interchange, it is feasible that the distribution of these trips to the system could be accomplished.

A procedure for performing this distribution by means of successive approximations has been proposed by Mr. Thomas J. Fratar (14, 15). By this procedure preliminary desire line volume estimates are made and subjected to a series of adjustments so that the total line volumes terminating in each tract approaches the estimated trips generated in that tract. The method roughly follows the Hardy Cross theory used in the moment-distribution analysis of stresses and in computing head losses

in water distribution systems (25).

Trip Desire Satisfaction

Such a procedure would require not only good estimates of total generated trips for each tract in the system, but also a distribution factor for each potential desire line connecting these tracts. These factors should reflect the mutual attraction existing between each pair of tracts. The capacity of other tracts to satisfy the trip desires or purposes of a particular tract would seem to be an essential consideration in determining the distribution of its trips. A knowledge of the proportions of trips by purpose generated by various land use classifications, then, appears to be of importance.

Observations have been made in Detroit and Washington, D.C., of the proportions by purpose of trips generated by zones of various land use and economic classifications (6). A similar summary of the Logansport and Richmond internal trips was impossible due to lack of information on trip purposes. However, it was possible to prepare a summary of trip distribution by land use.

The CBD and groups of industrial and residential tracts, having large employment or population and being nearly "pure" in land use, were chosen for this summary. The total daily car and truck trips generated by the CBD or by the selected group were classified according to the land use of the exchanging tracts. By classifying these trips in such a way as to indicate the predominant mixtures of land use in the connected tracts, it was hoped to reflect the capacities of the various land uses to satisfy the trip desires of CBD, residential, and

industrial tracts.

The summary of this analysis is in Table 15. An interesting amount of parallelism between the two cities can be seen, in spite of the varying amounts of trip opportunities to the various land use areas. One exception is the large per cent of the residential group trips which is attracted by industrial tracts in Richmond. This is probably explained by the larger number of industrial tracts and the larger employment which afford more opportunity for such trips. There are evidences of the high attraction between CBD's and residential tracts, and between industrial and residential tracts. The small amount of industrial-industrial and CBD-industrial attraction is also indicated.

Because of the parallelism, the data for the two cities were combined to form tentative figures for distributing trips where all conditions are similar to those in Logansport and Richmond. It is considered very probable, however, that differences in definition of the land use classifications or in criteria for delimiting tracts could very seriously alter these distribution figures. It is recommended that, in order to further investigate trip desires and the capacities of land use to satisfy them, more precise definitions of land use mixtures be employed. The use of such knowledge to estimate current or future trip distribution from a given land use area, and ultimately to estimate inter-tract travel patterns is entirely feasible.

Distribution Factors

It is certain that in addition to land use, other variables must also affect trip distribution and must, therefore, be taken into

Table 15

Trip Distribution by Land Use

No. of Tracts	Land Use Classification	Per Cent Distribution by Selected Tract Groups[1] CBD	Residential	Industrial
	Logansport[2]			
	No. of Selected Tracts	1	3	2
12	Residential	52.9	22.4	47.0
9	Residential-Rural	13.1	11.6	16.0
1	Residential-Recreational	6.6	3.4	4.1
2	Residential-Industrial	9.0	8.6	6.8
2	Residential-Commercial	11.1	9.3	6.7
2	Industrial	2.7	5.0	-
2	Industrial-Commercial	4.6	5.9	2.5
0	Industrial-Institutional	-	-	-
1	CBD	-	33.8	16.9
31	Total	100.0	100.0	100.0
	Richmond[2]			
	No. of Selected Tracts	1	3	3
7	Residential	42.0	15.8	41.8
10	Residential-Rural	16.5	14.8	17.5
2	Residential-Recreational	6.1	5.7	4.8
2	Residential-Industrial	6.8	5.4	4.9
3	Residential-Commercial	9.9	11.1	7.8
7	Industrial	14.2	22.9	5.4
1	Industrial-Commercial	3.4	3.9	5.4
2	Industrial-Institutional	1.1	1.3	0.7
1	CBD	-	19.1	11.7
35		100.0	100.0	100.0

(continued)

Table 15 (continued)

Trip Distribution by Land Use

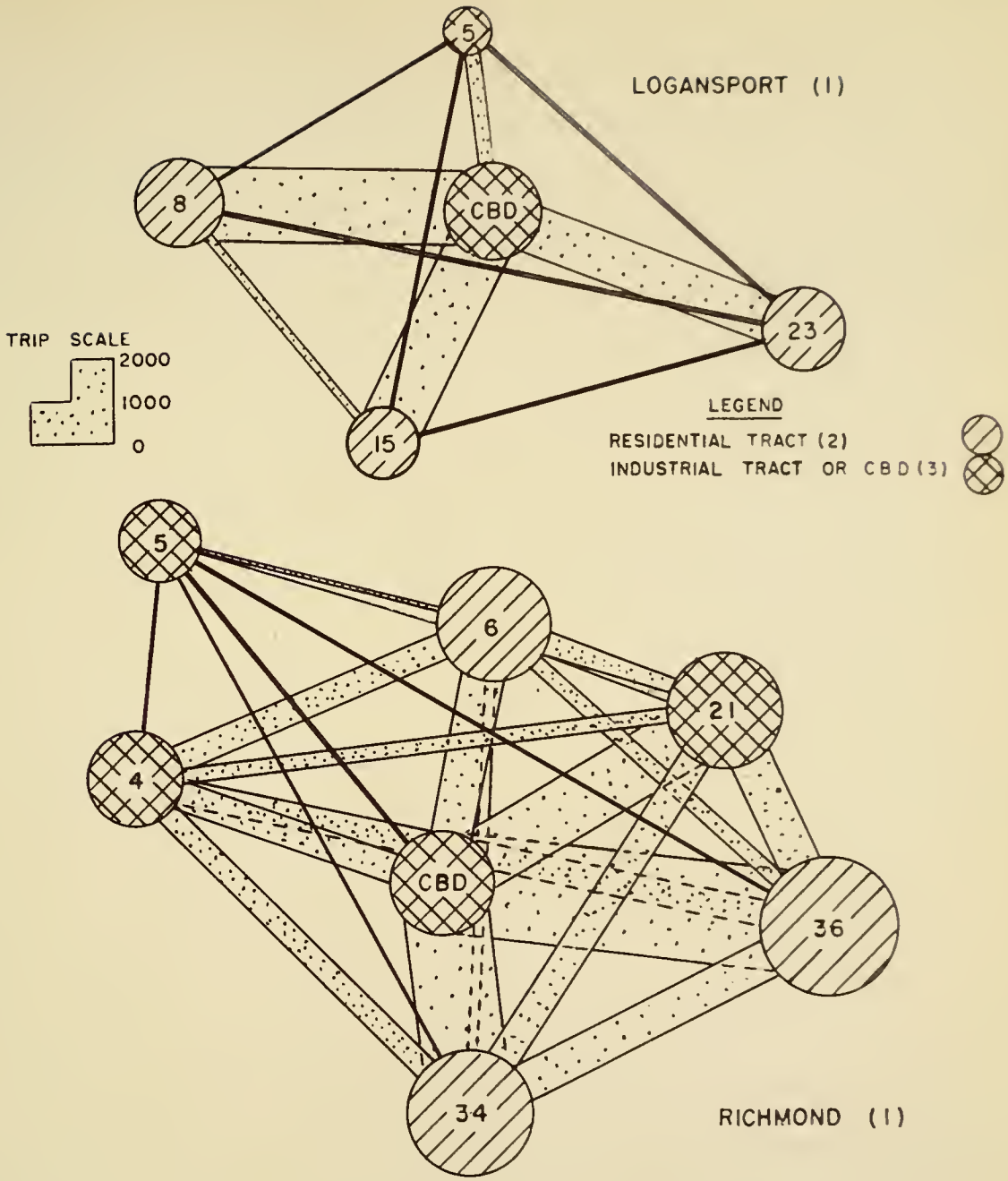
No. of Tracts	Land Use Classification	Per Cent Distribution by Selected Tract Groups[1]		
		CBD	Residential	Industrial
	Combined[2]			
	No. of Selected Tracts	2	6	5
19	Residential	47.0	17.9	42.6
19	Residential-Rural	14.9	13.8	17.2
3	Residential-Recreational	6.3	5.0	4.7
4	Residential-Industrial	7.7	6.4	5.2
5	Residential-Commercial	10.5	10.6	7.7
9	Industrial	9.0	17.2	4.6
3	Industrial-Commercial	4.0	4.5	5.0
2	Industrial-Institutional	0.6	0.9	0.5
2	CBD	-	23.7	12.5
66	Total	100.0	100.0	100.0

Notes:

1. Selection based on homogeneity of land use, population, and employment.

2. Source: Logansport and Richmond, Indiana O-D survey reports.

3. Intra-tract trips not included. Percentages based on total group-generated trips to and from all other tracts.



NOTES: (1) SELECTED SYSTEM OF O-D SURVEY TRACTS
(2) CIRCLE AREAS PROPORTIONAL TO POPULATIONS
(3) CIRCLE AREAS PROPORTIONAL TO EMPLOYMENT
INTER-TRACT DISTANCES NOT TO SCALE

EFFECT OF TRACT SIZE ON TRIP DISTRIBUTION

FIGURE 18

account in the development of distribution factors or attraction ratings to be attached to lines of desire. Mr. Bevis (7) defines these as factors of "friction", which have a retarding effect upon otherwise free trip movement.

Evidence that such factors are important is in the modified desire line graphs on Figure 18. From each of the studied cities a system was chosen, consisting of the tracts used in the summary on Table 15 and all daily car and truck trips between them. Areas of the circles are proportional to tract size, measured either by population or employment, and line widths represent volumes of exchanged trips.

A number of examples indicating influence of proximity, accessibility, or other factors in addition to tract size, can be seen in this figure. Although Logansport residential Tracts 8 and 23 have nearly the same population, Tract 8 exchanges 47 per cent more trips with the CBD. The Logansport CBD also attracts more trips from Tract 15 which is smaller than Tract 23. In Richmond, the trips exchanged by residential tracts 6, 34, and 36 show the same dissonance with tract size. Reference to Figures 1 and 2 may suggest that distance and accessibility may very well be the explaining factors.

On the other hand, trips distributed by the depicted industrial tracts seem to be more in accord with the size of the attracting tracts. This is exemplified by the pattern by which Tract 4 distributes its trips in the Richmond system. It would appear, then, that trip length may have less effect on the trips to or from work than it does on trips for other purposes.

This tends to bear out previous observances that the effect of

trip length is dependent upon trip purpose. The worker, who seems to make little effort to live near his work, will of necessity make long trips to work, but the grocery shopper will be more likely to pick the most convenient store. It has been suggested that in order to measure the effect of distance the exponent should vary from 0.5 for work or business trips and 2 for food and drug shopping or recreational trips to 5 for social trips and trips for "shopping goods"(6). Travel time or driving time has also been a proposed measure of one of the factors affecting the "split" of trips to areas which satisfy the purpose (10, 12).

It is fully expected, on the basis of past investigations and the support given by the Logansport and Richmond data, that ultimately a tract's total generated trips can be distributed by means of well-defined distribution factors. It appears necessary that these factors account in some way for attraction due to the proportions of generated trips requiring satisfaction of purpose in various other land areas, the size or capacity of other tracts to satisfy trip desires, and the trip lengths by time or distance to alternative tracts.

Application

In order to summarize some of the empirical relationships observed and demonstrate the limitations of their use in their present stage of development, an attempt was made to apply them to estimate some of the trip movements in the Lafayette-West Lafayette, Indiana, area. It was not expected that all important movements could be analyzed, not only because of the observed imperfections in the correlations, but also because of some characteristics of this area not present in the Logansport

and Richmond areas. While it was not possible to estimate the effects of these characteristics, it was considered possible to make estimates of certain basic movements which could be compared with those found in the 1952-53 traffic survey of the Lafayette-West Lafayette area.

Total Estimates

Two estimates were made in an attempt to obtain a concept of the general magnitude of internal trips in this area. It has been shown that the total trips generated within the Logansport and Richmond areas were not predictable using person-trip regression lines fit to data from other cities. However, it was considered possible that total car and truck trips could be estimated from their relationships with the area populations of Logansport and Richmond. It was also believed likely that total CBD trips could be predicted in the same manner.

The points representing daily internal car trips in each of the cities as related to metropolitan area population and the estimation lines fitted to the Logansport and Richmond points are shown in Figure 19. From these lines the estimated total car trips generated the Lafayette metropolitan area is about 102,000. The actual value according to the survey report is 89,312. The discrepancy may be due to several causes. Errors in estimated values of population or trips in any one of the cities could explain it. It is considered likely, however, that the estimation line is in error, since it is based on only two points. It is suggested that it may lie below its present locus with respect to the ordinate or that its slope may be reduced.

The estimate of CBD trips based on the Logansport and Richmond points is 24,000 and the comparative value is 22,003. While the

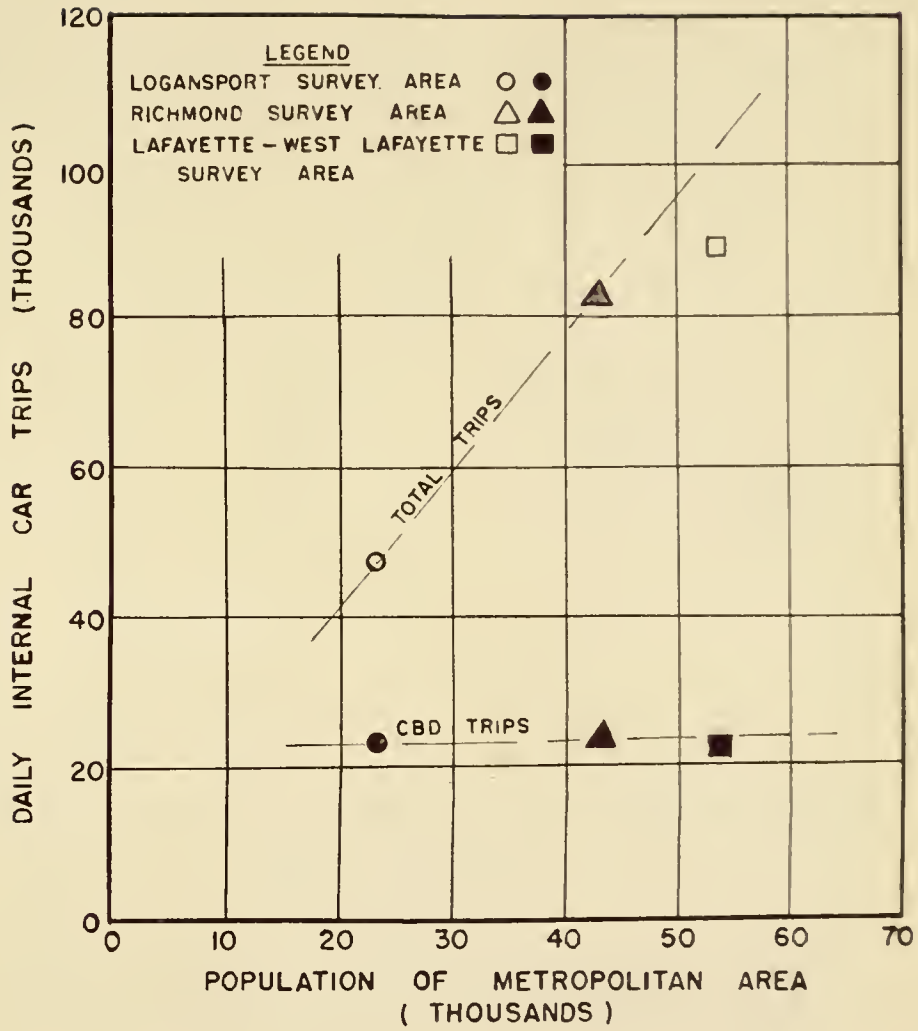
estimate appears accurate, considerable doubt must still be attached to the estimation line. Varying definitions of the CBD's in the three cities could very easily account for the flatness of the line, which must drop off very sharply to go through zero. This, again, would demonstrate the importance of that definition.

More points are needed to establish reliable lines, and even then it is possible that other factors may be needed to make estimates of total internal or CBD trips. If used with limitations the correlations shown in Figure 19 may provide a rough guide in obtaining a concept of the magnitude of trip frequency in an urban area.

Inter-Tract Estimates

While estimates of total trips generated by individual tracts are possible, they do not contribute to a picture of over-all internal movement unless they are distributed to lines of desire, because of the presently insufficient means to distribute trips, it was decided that estimates of inter-tract trips would be more likely to include the more important movements. On the basis of the foregoing investigations of urban characteristic-trip relationships the trip movements concluded to be the most basic and generally the most important are the CBD-residential trips, inter-residential trips, and residential-industrial trips.

The equations developed from the Logansport and Richmond data were used to estimate CBD-residential trips. The 25 residential tracts having the greatest population were selected for estimating this type of trip. The relation of each residential tract to the area's population distribution was required and a compactness chart (Figure 20) was made

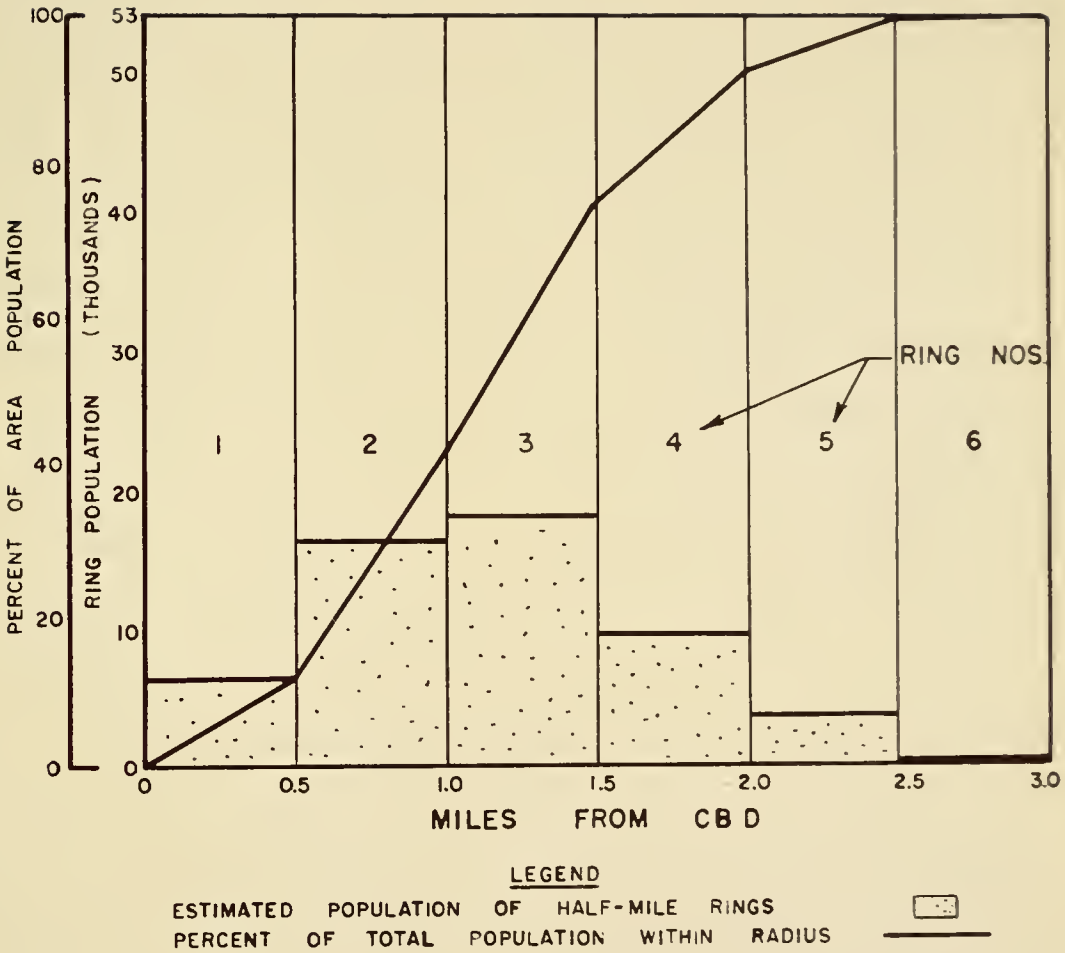


NOTES :

SOURCE : LOGANSPORT, INDIANA TRAFFIC SURVEY
SOURCE : RICHMOND, INDIANA TRAFFIC SURVEY
SOURCE : LAFAYETTE - WEST LAFAYETTE, INDIANA TRAFFIC SURVEY

RELATION OF CAR TRIPS AND AREA POPULATIONS

FIGURE 19



LAFAYETTE POPULATION COMPACTNESS

FIGURE 20

for this purpose. Distance, population, and ownership data were obtained in the same way they were for the Logansport and Richmond tracts. These data and the estimations of CBD-residential trips are in Table 16.

The rates at which inter-residential trips are exchanged were estimated by means of apparent regression lines fitted by freehand to the data plotted on Figure 16. The estimation lines so obtained are shown on Figure 21. Since the correlations in the Logansport and Richmond data were not perfect, lines for only two broad ownership classifications were used for estimating trips between residential tracts in the Lafayette area. The required data for going into this chart and the resulting estimates are shown in Table 17. Selecting the ten residential tracts with greatest population, estimates were made of trips between all possible pairs except those involving river crossings.

Trips between important industrial and residential tracts were estimated from a line fitted to the data plotted on Figure 17. However, since there was very little correlation evident on that figure, and since an exponential line appeared best for inter-residential data, the data were replotted on a semi-log grid. The exponential estimation line which seemed to best fit the data is shown on Figure 22. All necessary population, employment, and trip length information was obtained by the same procedure used in the Logansport and Richmond areas. Land use classifications were made similarly for all three areas. Eight of the most populated residential tracts and all industrial tracts with over 200 estimated employees were selected.

Table 16

Lafayette-West Lafayette

CBD-Residential Trip Estimates

Res.[1] Tract No.	Str.Line[2] Radius From CBD	Street[3] Dist. From CBD	Reg.[4] Pass. Cars	Est.[5] Pop'n	Persons Per Car	Per Cent Pop'n[6] Within Radius	Est.[7] CBD Trips
5	2.0	2.4	355	1480	4.17	92.2	320
10	1.8	1.9	453	1275	2.82	85.0	2292
11	1.5	1.6	510	1117	2.19	74.8	1454
14	1.3	1.6	594	1854	3.12	61.5	719
15	1.0	1.4	475	1130	2.38	41.8	1382
16	0.9	1.0	787	2456	3.12	36.0	1543
19	0.9	1.1	743	2693	3.63	36.0	1085
21	2.1	2.2	374	1064	2.85	93.6	969
33	0.3	0.3	284	1299	4.57	7.0	3
34	0.3	0.4	370	1164	3.14	7.0	0
39	0.3	0.4	380	1754	4.62	7.0	4
40	0.4	0.5	442	1984	4.49	9.2	22
41	0.8	1.0	390	1769	4.54	30.0	129
42	0.6	0.9	402	1534	3.82	17.6	80
45	1.1	1.4	478	2071	4.33	48.0	578
46	1.3	1.6	302	2024	6.71	61.5	0
55	2.0	2.3	415	2420	5.83	92.2	0
59	1.1	1.2	367	1676	4.57	48.0	360
60	0.6	0.6	336	1174	3.50	17.6	64
61	0.8	1.0	428	1456	3.40	30.0	621
63	1.5	1.7	461	1143	2.48	74.8	1194
66	1.5	1.9	435	1291	3.98	74.8	539
68	1.7	2.3	531	1570	2.96	82.5	1391
70	0.9	1.3	516	1458	2.82	36.0	1166
76	1.2	1.7	530	1658	3.12	55.0	1420

Notes:

1. Selected residential tracts having largest population.

2. Mileage between CBD and tract centers of gravity scaled from large tract map.

3. Street mileage between CBD and tract centers of gravity scaled from large tract and street maps along most convenient existing streets.

(continued).

Table 16 (continued)

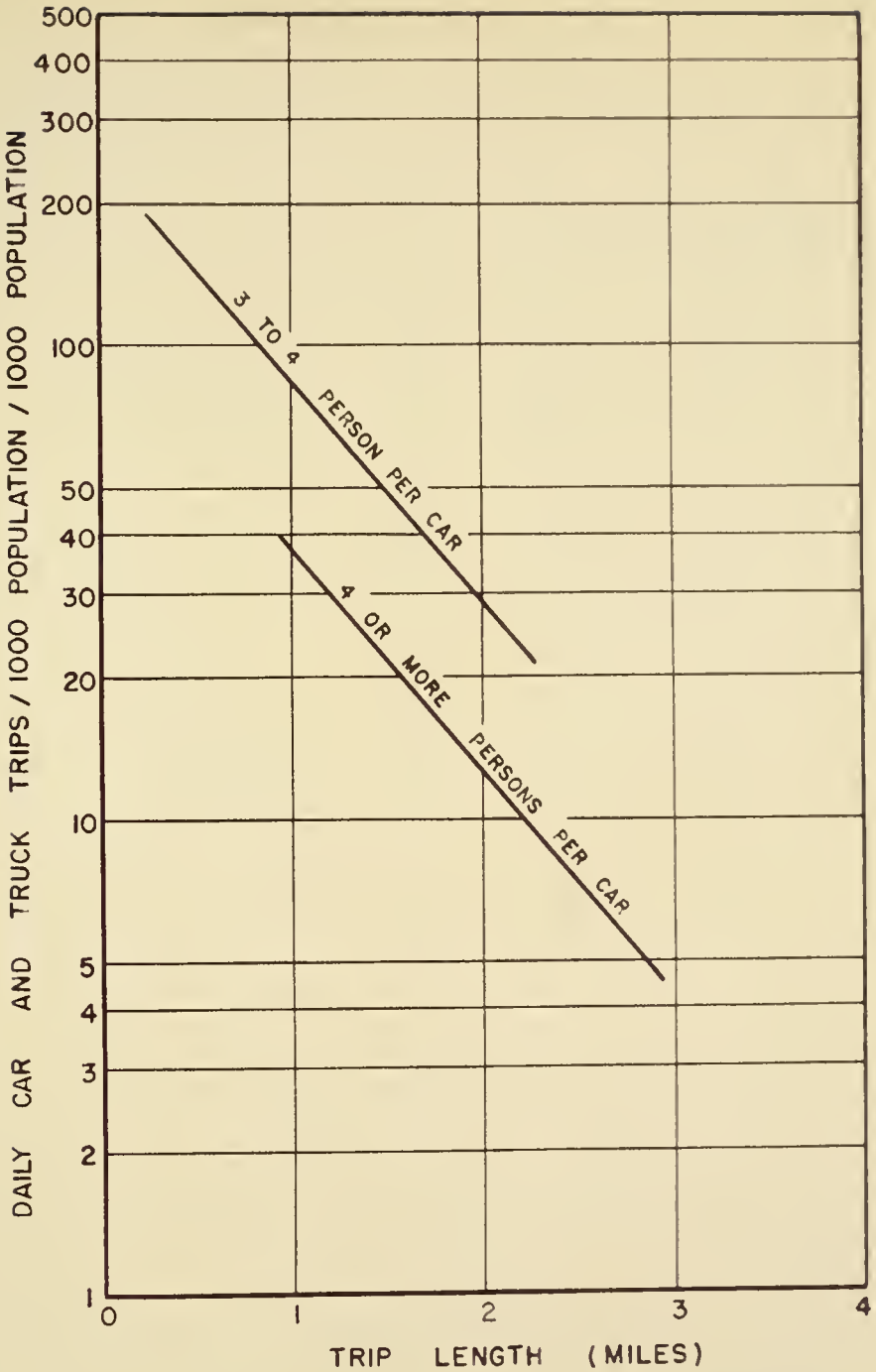
Notes (continued):

4. Source: Survey summary of official registration lists.

5. Population estimates based on 1950 Census counts, Sanborn maps, and land use field check.

6. Interpolated from ring population data shown in Figure 20.

7. Estimated from equations fitted to Logansport and Richmond, Indiana, data.



SOURCE : APPARENT CORRELATION IN LOGANSPORT AND RICHMOND DATA (SEE FIGURE 16)

INTER-RESIDENTIAL TRIP ESTIMATION LINES

FIGURE 21

Table 17

Inter-Residential Trip Estimates

Tract Pair[1]		Est. Pop'n[2]		Average Persons	Trip Length	Est. Trips per 1000 Pop'n	Est.
a	b	a	b	per car	(miles)	per 1000 Pop'n	Trips
14	16	1854	2456	3.12	0.72	112	510
14	19	1854	2693	3.40	0.85	99	494
16	19	2456	2693	3.40	0.53	150	992
39	40	1754	1984	4.55	0.31	76	264
39	41	1754	1769	4.58	0.68	52	161
39	45	1754	2071	4.46	1.04	36	131
39	46	1754	2024	5.54	1.28	27	96
39	55	1754	2420	5.25	2.00	12	51
40	41	1984	1769	4.51	0.52	62	218
40	45	1984	2071	4.41	0.90	41	168
40	46	1984	2024	5.39	1.80	15	60
40	55	1984	2420	5.14	1.71	17	82
41	45	1769	2071	4.42	0.38	72	264
41	46	1769	2024	5.48	0.67	52	186
41	55	1769	2420	5.20	1.34	26	111
45	46	2071	2024	5.25	0.32	76	319
45	55	2071	2420	5.03	1.37	25	125
46	55	2024	2420	6.20	1.18	31	152

Notes:

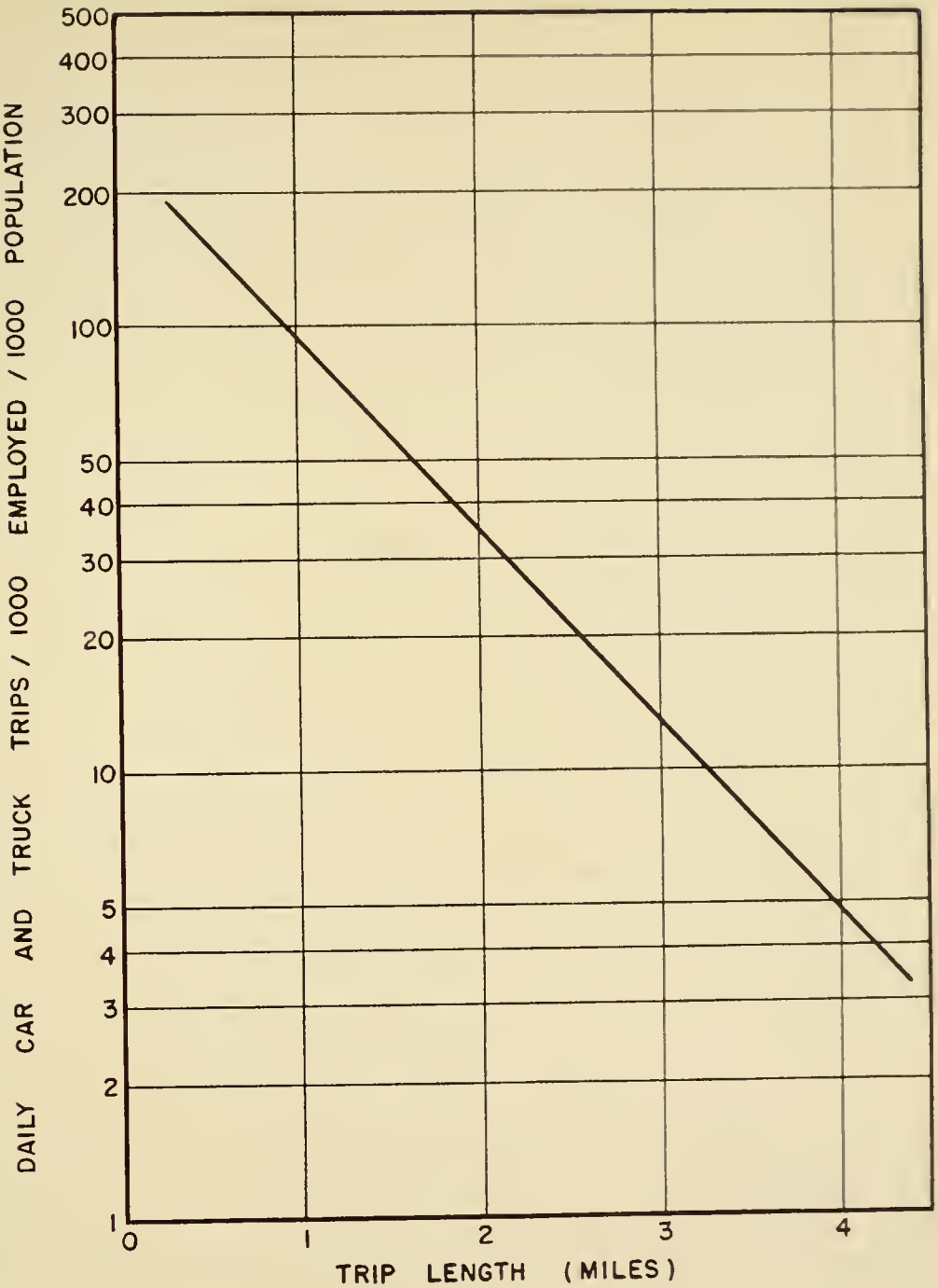
1. Selected pairs of predominantly residential tracts over 1000 population.

2. Population estimates based on census counts, Sanborn maps, and land use field check.

3. Averages based on pooled populations and registrations in both tracts; source; official registration lists.

4. Scaled street mileage between tract centers of gravity.

5. Generation rate estimated from Figure 21.



SOURCE : APPARENT CORRELATION IN RICHMOND DATA
(SEE FIGURE 17)

RESIDENTIAL - INDUSTRIAL TRIP ESTIMATION LINE

FIGURE 22

The required data and trip estimates between all possible pairs of these tracts are listed in Table 18.

Estimated trips for the selected CBD-residential movements are shown graphically on Figure 23 along with the comparative desire lines established by the 1952-53 post card O-D survey. Similar desire line charts, showing the estimated and actual inter-residential and residential-industrial movements, are on Figures 24 and 25. Not all heavy movements are shown in these charts, particularly those connected with Purdue University and several commercial centers outside the CBD. The values which were estimated, however, produce patterns quite similar to those determined by the survey.

The greatest departure from this similarity occurs with trips generated by industrial tract 44. Unlike all the other selected industrial tracts, this tract is centrally located and most trips to and from it are relatively short. This tends to substantiate the point that industrial or work trips are not as greatly affected by distance as are other types of trips. It is considered very likely that special studies of heavy industrial generators may be necessary to account for the industrial trip distribution.

Because of the numbers of estimated values involved and the empirical relationships used, the similarity of the estimated and actual desire lines is particularly encouraging.

Table 18

Residential-Industrial Trip Estimates

Tract Pair[1] Res.	Ind.	Est.[2] Pop'n Resid. Tract	Est.[3] Empl. Indust. Tract	Trip[4] Length (Miles)	Est.[5] Trips per 1000 Empl. per 1000 Pop'n.	Est. Trips.
19	44	2693	953	1.88	39.0	100
19	49	2693	650	3.40	8.6	15
19	56	2693	800	3.05	12.0	26
19	67	2693	1190	3.40	8.6	28
19	78	2693	2290	3.30	9.6	60
19	80	2693	610	4.15	4.1	7
39	44	1754	953	0.73	120.0	201
39	49	1754	650	2.28	26.5	30
39	56	1754	800	1.92	37.0	52
39	67	1754	1190	2.49	21.0	44
39	78	1754	2290	2.35	24.0	96
39	80	1754	610	3.21	10.4	11
40	44	1984	953	0.63	130.0	246
40	49	1984	650	2.18	28.5	37
40	56	1984	800	1.74	44.0	70
40	67	1984	1190	2.17	29.0	68
40	78	1984	2290	2.03	33.0	150
40	80	1984	610	2.89	14.5	18
41	44	1769	953	0.57	140.0	236
41	49	1769	650	2.17	29.0	33
41	56	1769	800	1.41	62.0	88
41	67	1769	1190	2.55	20.0	42
41	78	1769	2290	2.29	26.0	105
41	80	1769	610	3.25	10.0	11
45	44	2071	953	0.45	160.0	316
45	49	2071	650	1.95	36.0	48
45	56	2071	800	1.68	48.0	174
45	67	2071	1190	2.88	14.4	35
45	78	2071	2290	3.12	11.2	53
45	80	2071	610	3.58	7.4	9
46	44	2024	953	0.57	144.0	278
46	49	2024	650	1.97	35.0	46
46	56	2024	800	1.88	39.0	63
46	67	2024	1190	3.30	9.6	23
46	78	2024	2290	3.54	7.6	35
46	80	2024	610	4.00	4.8	6

(continued)

Table 18 (continued)

Residential-Industrial Trip Estimates

Tract Res.	Pair[1] Ind.	Est.[2] Pop'n Resid. Tract	Est.[3] Empl. Indust. Tract	Trip[4] Length (Miles)	Est.[5] Trips per 1000 Empl. per 1000 Pop'n	Est. Trips
55	44	2420	953	1.62	50.0	115
55	49	2420	650	1.48	58.0	91
55	56	2420	800	1.15	80.0	155
55	67	2420	1190	2.28	26.0	75
55	78	2420	2290	2.86	14.6	81
55	80	2420	610	3.48	8.1	12
59	44	1676	953	1.68	48.0	77
59	49	1676	650	3.35	9.0	10
59	56	1676	800	1.27	71.0	95
59	67	1676	1190	1.39	64.0	128
59	78	1676	2290	1.42	61.0	234
59	80	1676	610	1.59	52.0	53

Notes:

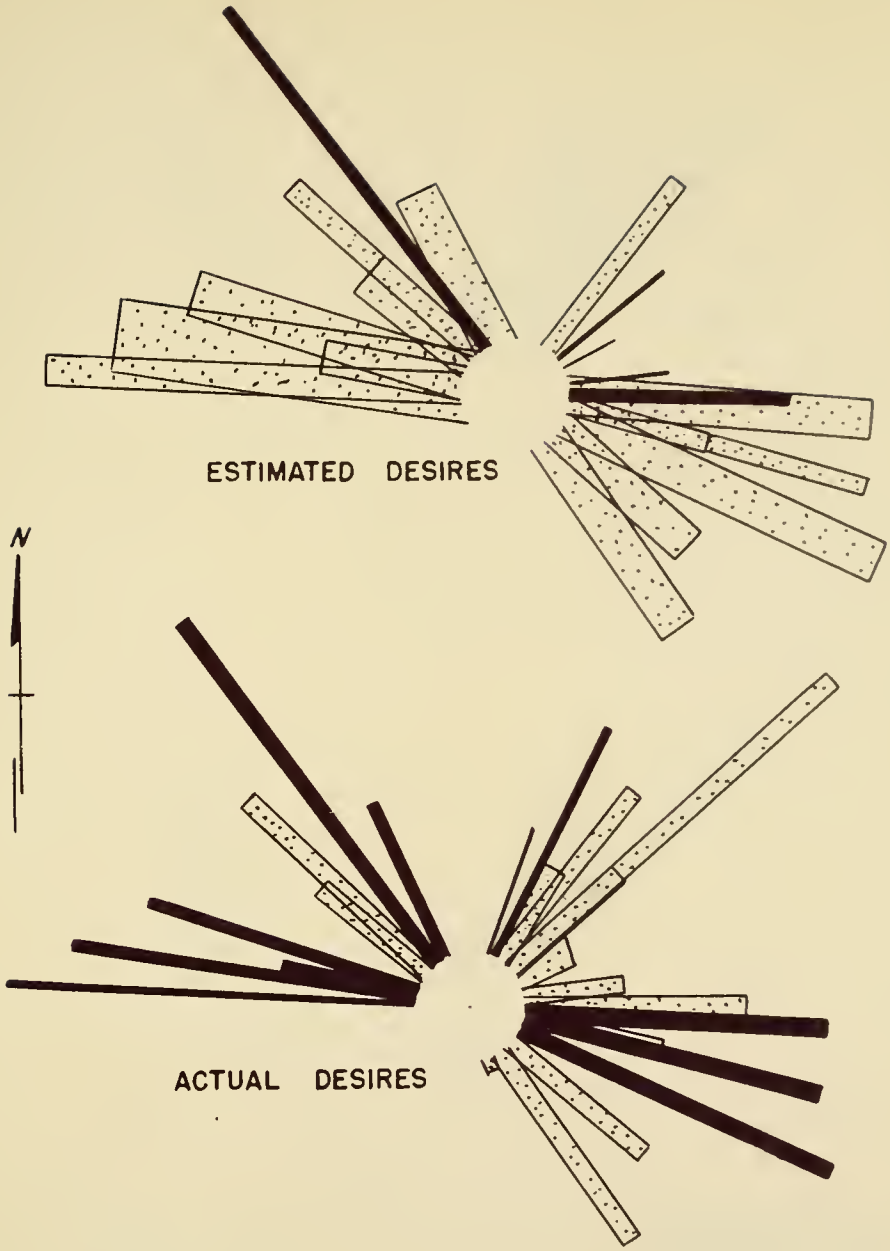
1. Pairs of Lafayette-West Lafayette tracts having predominantly residential and industrial land use; selection based on tract sizes and relationships.

2. Population estimates based on census counts, Sanborn maps, and land use field check.

3. Employment estimates based on Indiana Employment Security Division records as of date of survey.

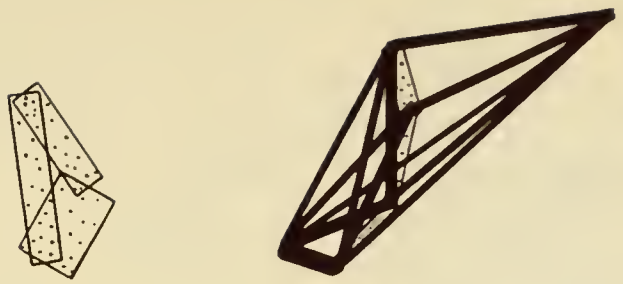
4. Street mileage between the tract pair scaled from large tract and street maps.

5. Estimate rate of exchange read from Figure 22.

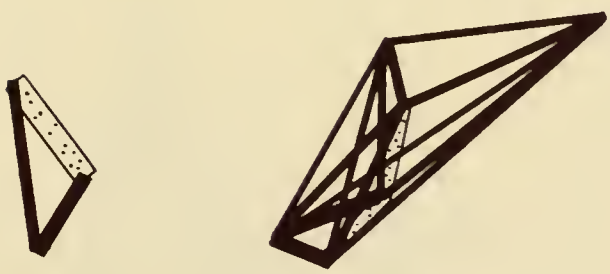


ESTIMATED AND ACTUAL C B D - RESIDENTIAL DESIRES

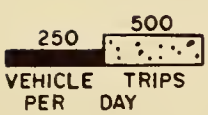
FIGURE 23

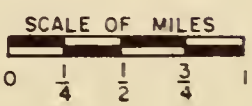


ESTIMATED DESIRES



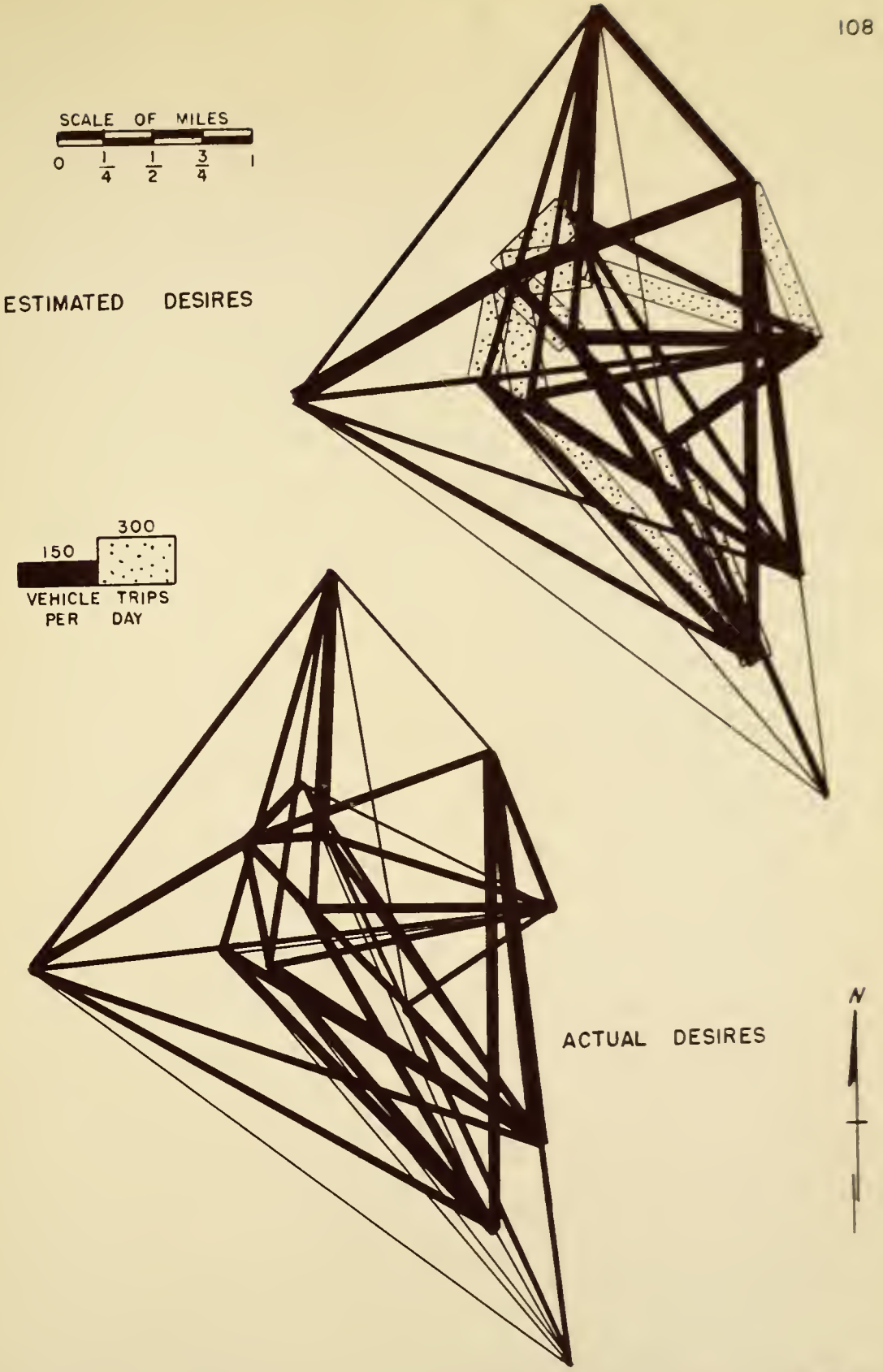
ACTUAL DESIRES





ESTIMATED AND ACTUAL INTER - RESIDENTIAL DESIRES

FIGURE 24



ESTIMATED AND ACTUAL RESIDENTIAL-INDUSTRIAL DESIRES

FIGURE 25

CONCLUSIONS AND RECOMMENDATIONS

Only a limited number of observations could be made in this study because of certain inadequacies of the O-D survey data which were not collected with consideration of an analysis such as this. Due to the number of approximated quantities involved, further limitations are necessarily affixed to the conclusions drawn from the observations which were made. However, the indications of definite relationships of urban characteristics and travel patterns which were discovered are, in a sense, given even greater significance by the fact that the data were not ideally defined. It may be reasonably supposed that greater accuracy in measuring trip volumes generated by very specific land use zones whose characteristic are well-defined, would result in even more consistency of relationship than was observed in this study.

Little success was experienced in estimating total person trips generated in the Logansport or Richmond areas or in their central business districts on the basis of population-trip relationships found in other cities. This was believed to be due chiefly to somewhat differing definitions of the areas called "metropolitan area" and "CBD". The estimate of total car trips in the Lafayette area, based on a very preliminary estimation line fit to the Logansport and Richmond data, was somewhat better, but suggested that factors other than population may affect generation of total trips.

Similar estimates of total internal work trips could not be made because complete purpose-of-trip information was not obtained in any of the three cities. Except to obtain a general concept of trip magnitude total area or work trips are relatively unimportant. The importance of total CBD-generated trips may warrant further investigations. It is recommended that attention be given to a more specific definition of the area called the CBD and an analysis of effects other than population, such as outlying commercial zones.

The population of residential tracts shows the highest correlation with their generated trips than any other single characteristic in the cities investigated. The correlation was not perfect, however. The rate of generation, expressed in car trips per dwelling, was seen to be influenced by ownership or cars per dwelling, but not in the same manner found in the Detroit study. The rate showed very little correlation with dwelling density or distance from the CBD. There were evidences of strong relationships between trips per residential acre and distance from CBD, between trips per dwelling and cars per capita, and between trips per capita and cars per capita. In order to approach a reliable procedure for estimating trips generated by any residential tract, it is recommended that further consideration be given to the isolation of 'pure' residential land and to the combined effects of population, ownership, and distance from the CBD.

Population may very well be the starting point for estimating trips generated by tracts having predominant land use other than residential. Trip generation in Richmond and Logansport tracts

containing commercial, institutional, and recreational attractions was influenced to some extent by population as well. This influence was not seen to affect the generation of industrial tracts. While it was found that land varies too greatly in intensity of use to allow the setting up of standard rates of generation by acre of land use, rates based on size measurements of various generators appeared feasible. It is highly recommended that further investigation be conducted to establish universal values of trip generation rate for individual types of establishments or generators. Such rates, with provision for modifications due to regional or peculiar situations, might ultimately provide the key to estimating trip volumes, current and future.

The combined effects of ownership, trip length, and population compactness permitted limited estimates of trips between residential tracts and the central business districts of the studied cities. The net regression was not perfect, however, and more stable or well-defined data and inclusion of additional characteristics are believed necessary for obtaining reliable estimation equations. The graphical procedure for arriving at the net regression lines appears to be well-suited to urban characteristic-trip data. It is believed that the net rather than individual effects of independent variables upon trip generation or exchange will be necessary in the development of estimation techniques.

Trips between pairs of residential tracts in the studied cities appeared to be effected by population and car ownership in each tract and by the distance between them. The rates of inter-

residential exchange are higher for these cities near or below 50,000 population than they are in larger cities, and decrease with distance following what may be an exponential decay pattern. It is recommended that further research be directed to the analysis of residential-residential trips, possibly utilizing the theory of magnetic attraction.

Although trips between industrial and residential tracts are undoubtedly effected by their respective employment and population, the exchange rate in trips per 1,000 employed per 1,000 population showed only a little correlation with trip length. A different approach is suggested for analyzing this type of trip. Estimates of the labor force of each residential zone may be necessary. It is considered very possible that special studies of large industrial traffic generators will remain the only reliable means of estimating their trip distribution.

In the course of performing the investigations herein reported, it was noted that every one of the variables which showed potential usefulness in estimating trips was a quantity that can be predicted for some future date. It can be expected that ultimately, good predicted values for urban characteristics coupled with well-defined empirical relationships with trip patterns will be the means of providing invaluable predictions of basic urban traffic needs.

GLOSSARY OF TERMS

Most of the terms used in this paper are defined in the text or are in fairly common usage among persons interested in traffic studies and travel patterns. Some, however, may be somewhat unique in their definition for the purposes of this study and are listed for the convenience of the reader.

1. Survey Area. This term is used to designate that area outlined by the cordon line established during the traffic surveys of the three studied urban communities, and is used synonomously with metropolitan area. In the original establishment of all three areas such factors as land use, urban influence, vehicle interception points and over-all study objectives were taken into account.

2. Cordon. The cordon is the imaginary line delimiting the survey area.

3. Tracts. Tracts are the divisions of the survey areas which were determined during the three traffic surveys, and which generally were delineated so as to separate areas of different land use for the convenience of analysis.

4. Rings. This term describes circular bands of area within the cordon, separated by circles concentric about the central business district.

5. Center of Gravity. The center of gravity of a tract is the apparent center of its developed land or vehicular activity. This point is used as the average point of origin and destination of all trips generated by a tract.

6. Generated Trips. Generated trips are all trips originating and ending in an area during an average weekday.

7. O-D Study. An origin-destination survey or study is one which is conducted to determine the origins and destinations of trips.

8. CBD. The central business districts of the studied metropolitan areas are the tracts or limited areas which are centrally located and contain the principal business, retail, theater, and hotel establishments.

9. Tract Pair. This term describes any two tracts having an exchange of trips subject to investigation.

10. Exchanged Trips. These are average weekday trips having both origin and destination in a tract pair.

11. Residential. This term describes land upon which there are dwellings and residences.

12. Industrial. Areas which contain factories, shops, plants, and other industrial trip generators are described as industrial.

13. Commercial. Commercial areas are those which include stores, offices, and other commercial establishments outside the CBD.

14. Institutional. Schools, homes, and other public institutions comprise the institutional land use areas.

15. Recreational. This describes land used for parks, golf courses, or other amusement and recreational places.

16. Rural. Land which is principally farmed or undeveloped is described as rural.

17. Shopping Goods. Goods for which the retail consumer "shops", is less likely to buy on impulse, and will travel considerable distance are called shopping goods.

18. Convenience Goods. Consumer items which a customer purchases daily or weekly and for which he is generally unwilling to travel much distance are referred to as convenience goods.

19. Person Trip. A continuous trip from origin to destination made by a person, either driver or passenger, is called a person trip.

20. Vehicle Trip. A vehicle trip is a continuous trip from origin to destination made by one vehicle or driver.

21. Inter-Tract Trip. A trip between any two tracts is an inter-tract trip.

22. CBD-Residential Trip. This is a trip between a CBD and a tract having a predominantly residential land use.

23. Inter-Residential or Residential-Residential Trip. This is a trip between two tracts which are primarily residential.

24. Residential-Industrial Trip. This is any trip between a residential and industrial tract.

25. Pure Land Use Areas. These are areas supporting a single urban development with no mixture of uses having dissimilar trip generation characteristics.

BIBLIOGRAPHY

1. Wynn, F. H., "Infra-City Traffic Movements", Bulletin 119, Highway Research Board, 1955.

2. Matson, T. M., "Characteristics of Urban Origin and Destination", Traffic Engineering, Vol. XXI, No. 8, p. 271, May, 1951.

3. Wynn, F. H., Traffic Engineering: Characteristics, Vol. IA, Course Notes, T.E. 210, The Institute of Transportation and Traffic Engineering, University of California, 1955.

4. Wynn, F. H., "Is This Trip Necessary?", A paper presented at a meeting of the American Society of Planning Officials, Montreal, Canada, 1955.

5. Row, A. T., "An Approach to O-D Data Analysis", Traffic Quarterly, Vol. IX, No. 1, pp. 105-122, January, 1955.

6. Carroll, J. D., Jr., "Forecasting Traffic Movement", Unpublished draft of a portion of Vol. 1 of the report of the Detroit Metropolitan Area Traffic Study, May, 1955.

7. Bevis, H. W., "An Analysis of the Factors Affecting Zonal Interchange Volumes", An unpublished paper produced in conjunction with the Detroit Metropolitan Area Traffic Study, 1955.

8. "The Relationship Between Over-the-Road and Geometric Measures of Trip Distance for the Detroit Area", An unpublished paper produced in conjunction with the Detroit Metropolitan Area Traffic Study, 1955.

9. Carroll, J.D., Jr., "Defining Urban Trade Areas", Traffic Quarterly, Vol. IX, No. 2, p. 149, April, 1955.

10. Conner, M.A. and Hiller, S.H., "Surveys in Miami Show Stability of Origin-Destination Patterns", Traffic Quarterly, Vol. VIII, No. 4, pp. 454-471, October, 1954.

11. Voorhees, A. M., Sharpe, G.B., and Stegmaier, J. T., "Shopping Habits and Travel Patterns", Special Report 11-B, Highway Research Board, 1955.

12. Casey, H. J., Jr., "The Law of Retail Gravitation Applied to Traffic Engineering," Traffic Quarterly, Vol. IX, No. 3, July, 1955.

13. Hitchcock, S.T., "Influence of Population, Sales, and Employment on Parking", Proceedings, Highway Research Board, Vol. 32, pp. 464-485, 1953.

14. Fratar, T. J., "Forecasting Interzonal Vehicular Trips by Successive Approximations", Abstracts, Highway Research Board, Vol. 23, No. 11, pp. 41-43, December, 1953.

15. Fratar, T. J., "Vehicular Trip Distribution by Successive Approximations", Traffic Quarterly, Vol. VIII, No. 1, pp. 53-65, January, 1954.

16. Carril, R. R., "A Method of Forecasting Traffic Based on Anticipated Land Use and Current Travel Habits", Abstracts, Highway Research Board, Vol. 21, No. 11, pp. 33-34, December, 1951.

17. Highway Research Review, Highway Research Board, No. 4, p. 178, November, 1955.

18. Logansport, Indiana, Traffic Survey Report, State Highway Commission of Indiana, 1952.

19. Kell, J. H., "Comparison of Two Methods of Internal Origin-Destination Surveys", Engineering Bulletin, Research Series No. 118, Engineering Experiment Station, Purdue University, Vol. XXXVII, No. 1, January, 1953.

20. Richmond, Indiana, Traffic Survey Report, State Highway Department of Indiana, 1954.

21. "Lafayette-West Lafayette, Indiana, Survey Report", State Highway Department of Indiana, Unpublished draft, 1955.

22. Voorhees, Alan M., "Basic Characteristics of Work Trips", Unpublished thesis,Bureau of Highway Traffic, Yale, 1952.

23. "Average Weekday Trips by Residents of Selected Urban Subdivisions of Various Types as Related to Economic Characteristics", Table compiled by the Highway Transport Research Branch, Bureau of Public Roads, from the Washington, D.C., Metropolitan Area Transportation Study, 1948.

24. Ezekiel, Mordecai, "Short-Cut Methods of Determining Net Regression Lines and Curves", Chapter 16, Methods of Correlation Analysis, John Wiley and Sons, New York, 1941.

25. Urquhart, L.C., et. al., Civil Engineering Handbook, pp. 495-499, 941-944, McGraw-Hill Book Co., Inc., Third Edition, 1950.